PNEUMATIC

TOWER FOUNDATIONS

OF THE

EAST RIVER

SUSPENSION BRIDGE.

W. A. ROEBLING.

1873.

New York:

AVERELL & PECKETT, Printers, 20 & 22 Gold Street

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PREFACE.

The following pages comprise chiefly the annual reports on the progress of the East River Suspension Bridge, from 1869 to 1872.

Having heretofore appeared in newspaper form only, they are now presented as a connected narrative, giving a detailed account of the work from its inception to the present time, when the foundations are finished and the towers have already reached more than half their intended height. They present, a history of the successful completion of the two largest pneumatic foundations extant, as regards area of base, although surpassed in depth by those of St Louis.

Being the first application of timber caissons on a large scale, it may be of interest to state, that, at the time of writing, with already more than two-thirds of the ultimate pressure on the base of the Brooklyn tower, the total settle ment has only been five-eighths of an inch, and of uniform character all around.

An introductory chapter is added, giving an outline of the general plan of the structure, its principal dimensions and location, as originally designed by the late John A. Roebling, and described by him in his preliminary report of 1867; together with the few modifications made since then.

BROOKLYN, OCT. 1st 1872.

INTRODUCTORY REMARKS.

The East River Bridge will form a suspended highway, connecting New York and Brooklyn, cities of respectively one million, and four hundred thousand inhabitants. The location of the terminus in New York is opposite the City Hall, in Chatham street; and in Brooklyn, in the square bounded by Fulton, Sands, Washington, and Prospect streets, comprising a total length of five thousand nine hundred and eighty-nine feet. It forms an air line from the City Hall to the square above mentioned.

Of this whole length, three thousand four hundred and fifty-five feet are suspended in three main openings. The central span will cross the river from pier-line to pier-line, without impeding navigation, in one single span of one thousand five hundred and ninety-five feet, six inches, from centre to centre of tower. From each tower towards the land side, half-spans will be supported by the land cables, nine hundred and thirty feet long each, measuring from the centre of tower to face of anchor-wall.

From the face of the anchor-wall, on the New York side, a distance remains of one thousand five hundred and sixty-two feet, six inches, to Chatham street, and from the anchor-wall to the Brooklyn terminus, a distance of nine hundred and seventy-one feet.

These distances, between the anchorages and termini, are known as the *approaches*. These latter will be supported by iron girders and trusses, and will rest at short intervals upon small piers of masonry or iron columns, located within the blocks of buildings which will be crossed and occupied. These pillars will form part of the walls needed for the division of the occupied ground, into stores, dwellings, or offices.

In every such case the bridge floor will be constructed fire and water proof; serving as a roof to the blocks of houses underneath. The streets will be crossed by iron girders and trusses, twelve in number.

There will be one uniform grade of three feet, three inches per one hundred feet from the New York terminus to the centre of the Bridge, and the same from the Brooklyn anchorage. That of the Brooklyn approach will be less, only two feet, nine inches per one hundred owing to the greater elevation of the terminus.

The roadway will pass the towers at an elevation of one hundred and nineteen feet, and in the centre of the main span, the elevation in the clear of the lower chord of the Bridge, will be one hundred and thirty-five feet above mean high water, or one hundred and forty feet above low water.

This elevation was fixed by special Act of Congress, being an increase of five feet over that of the original plan.

It is sufficient to permit the unobstructed passage of all schooners, barques, brigs and steamers, as well as ships below a thousand tons. Ships above that tonnage will have to lower their upper spars. The amount of such tonnage is however only one-tenth of that passing under the Bridge, and the number of such vessel not one in two hundred, diminishing moreover in numbers from year to year, as the commerce of the world is carried on more and more by steamers.

The suspended superstructure will consist of an iron framing eighty-five feet in width from out to out, suspended from four main cables by wire rope suspenders attached to iron floor-beams, which are placed seven feet six inches apart. The flooring is further divided into five spaces by six lines of iron trusses, of which the two centre-lines have a depth of twelve feet, and the others, of eight feet; the lower chords being placed below the iron floor beams.

The outer spaces have a width in the clear between the truss posts of eighteen feet, one inch, and accommodate each, two lines of iron tramways for ordinary vehicle travel, as well as for street cars, drawn either singly, by horses, or in pairs, by light dummies. The next two spaces are thirteen feet two

inches wide each, provided with iron rails for the running of two passenger trains back and forward alternately.

These trains will be attached to an endless wire-rope, propelled by a stationary engine, which is located on the Brooklyn side, underneath the floor, the two tracks being operated like an incline plane, with a speed of twenty miles per hour, the whole transit occupying only five minutes from terminus to terminus.

From eight to ten compartment cars, each fifty feet long, and holding one hundred persons, will constitute a train. By means of opposite doors on the side of the cars, and wide platforms, it is possible to fill and empty the trains in two minutes, without producing interference between the going and coming passengers. For this reason the Bridge is widened out to one hundred feet at this point.

In addition to these trains, arrangements are being made for a connection with the underground railroad, (New York Central) at the New York City Hall, by which passenger cars can be passed over the Bridge to Brooklyn without change. These cars will pass under Chatham street, and be transferred to the level of the Bridge by a hydraulic lift.

The Central or fifth division of the Bridge floor forms a promenade for foot travel, fifteen feet in width. It is elevated five feet above the roadway, affording a view over both sides of the Bridge.

CABLES.

The Bridge is supported by four main cables; two outer ones, and two near the middle of the flooring. They will be sixteen inches in diameter; composed of galvanized, tempered, cast steel wire, No. 6 gauge; having a strength of one hundred and sixty thousand pounds per square inch of section. The cables are aided by a system of one hundred and four stays in each quarter. They together will uphold the superstructure of the main span, the aggregate weight of which, inclusive of cables, will be five thousand tons.

TOWERS.

The two main towers form the principal features of the

work. At the water-line the New York tower has a length in the direction of the river of one hundred and forty-one feet, and a width of fifty-nine feet. On top of the timber foundation these dimensions are respectively one hundred and fifty-seven feet, and seventy-seven feet, while the base of the foundation measures one hundred and seventy-two feet by one hundred and two feet.

The elevation of the floor is one hundred and nineteen feet above high water; the height of the roofing above the floor, one hundred and forty-nine feet, making a total height of two hundred and sixty-eight feet from high water to the roof, without balustrade; or from the base of the foundation to top of the balustrade three hundred and fifty-four feet. The towers consist essentially of three main shafts, united below the floor line by connecting walls, the latter enclosing two square, hollow spaces for the purpose of saving masonry. Above the floor these shafts extend singly for a height of eighty feet; here they are united by two gothic arches of thirty-six feet rise, covering the roadways.

The facestone throughout are Granite, and the backing also, with the exception of a small portion of Limestone. The backing throughout is *cut* backing, thus reducing the spaces occupied by cement and concrete to less than 8 per cent.

The quantity of masonry in the New York tower from the timber to the summit is 44,000 yards, giving a weight of about 93,000 tons on top of the timber foundation, superstructure included. These quantities do not include the timber and concrete foundation below the masonry. Including the latter we have a pressure at the base of the entire structure of six and a-half tons per square foot. On top of the timber, ten tons; on the masonry at the water line, thirteen and a-half tons, and at the base of the Central Shaft at the Floor line, twenty-six tons!

To meet these exceptionally great pressures, the masonry has throughout been laid in the most conscientious manner, and all by day's work.

The Anchorages

Will each contain 33,000 yards of masonry. No rock being available, it is necessary to provide artificial foundations, extending to the water level with an excavation of twenty feet, that in Brooklyn consisting of a timber platform, and that in New York of piles. The Anchorage forms a mass of stone, one hundred and twenty-nine feet by one hundred and nineteen feet at the base, and one hundred and seventeen by one hundred and four at the top. The height is eighty-nine feet above the river, it being necessary to carry it up to the grade of the floor.

The four cables enter the masonry at an elevation of eighty-two feet, and, after passing into the wall for twenty-five feet, they form a connection with the chains. The latter consist of cast steel bars, thirteen feet long and ten inches wide, by one and a-half inches thick, arranged in ten sections, each containing nineteen bars and forming in all four curved lines extending from the cables to the anchor-plates. The connections are made by six inch steel pins.

The four anchor-plates are located at the base of the masonry. They consist of casting, oval in outline, with radial arms, having a dimension of nineteen feet by seventeen feet, and depth of three feet, weighing twenty-five tons each. The arrangement of the anchor walls is such as to have two large spaces in each, eighty feet long by twenty feet wide, and divided into six stories, serving for warehouses above and for an underground railway passage in the lower story.

In March, 1869, the financial affairs of the Company were placed upon such a basis as to warrant the commencement of the preliminary operations usually connected with such a work. A board of Consulting Engineers were convened at the request of Mr. John A. Roebling, with the object of examining into the general feasibility of the work and making a report thereon. Its members consisted of Messrs. Allen, Latrobe, Kirkwood, McAlpine, Adams, Steele, and Serrel. Their deliberations, substantially endorsing the plans, are contained in a report written by the President of the Board, Mr. Horatio Allen.

In May, 1869, a commission of three Government Engineers, General Wright, General Newton, and Major King, were appointed, by the War Department, in compliance with an act of Congress, to report upon the East River Bridge, in regard to its being an obstruction to navigation as well as upon the general feasibility of the project.

Those gentlemen recommended an increase of five feet in the elevation of the floor of the main span of the Bridge, fixing it at one hundred and thirty-five feet above mean high spring tides.

In order to avoid the increase in grade caused by this additional elevation, and also to save the increased amount of masonry in towers and approaches, which would have entailed an extra expense of $300,000; it was determined to overcome it by making an entire change in the plan of the superstructure, throwing the trusses altogether above the floor in place of partly above and partly below as contemplated in the original plan. At the same time the floor of the Bridge was widened from eighty to eighty-five feet, to accommodate two double tracks for vehicles in place of two single tracts. The Government Commission also decided that no part of the permanent masonry of the towers above water should extend beyond the pier lines, and that no part of the foundation of the towers should extend above the natural bed of the river, beyond the pier line. In June work was commenced on the

Surveys.

The general line known as the park route had before been determined on, but no actual line had ever been located upon the ground, the proposed line having simply been traced upon the best maps procurable. Several centre lines were run on trial. The one finally fixed upon narrowly escapes the Fulton Ferry slip on the Brooklyn side, and the Williamsburgh Ferry on the New York shore, being restricted at the same time to the two termini fixed by the charter.

In the location of most bridges some attention is paid to the difficulties likely to be incurred in getting foundations

for piers, in making approaches, etc.; but here such considerations had to be ignored, and the towers and anchorages placed wherever the exigencies of the case brought them.

A minute and detailed survey of all the property on the line of the Bridge was then made and the location of the Brooklyn tower fixed upon. This work consumed most of the Summer months of 1869.

It was while engaged in locating the position of the Brooklyn tower that Mr. John A. Roebling met with a lamentable accident—the crushing of his right foot by the shock of a ferry boat against the fender rack of spring piles on which he was standing. Lock-jaw speedily set in, and after sixteen days of extreme suffering, terminated in death.

For a period, operations on the bridge came to a stand still.

In August, the writer was appointed Chief Engineer of the work. The Executive Committee of the Bridge Company, were likewise empowered to proceed with the necessary steps for securing the site of the Brooklyn foundation, making a contract for the caisson, and preparing the site for its reception. Mr. Horatio Allen was appointed consulting Engineer during the foundation work, and to Messrs. Webb & Bell, of Greenpoint, was awarded the contract for building and launching the timber caisson.

THE BROOKLYN FOUNDATION.

One trial boring, made in 1867, showed gniess rock at a depth of ninety-six feet below high water. The strata penetrated consisted, besides the surface filling, principally of hard pan and alternate layers of trap boulders imbedded in sand and clay. Below a depth of fifty to sixty feet the material was so compact, that the bore hole stood without tubing for weeks. No necessity existed therefore for going down to rock, since a depth of fifty feet would suffice.

But the great desideratum to be attained was a foundation of a uniform character over the entire space, whatever the depth might be. It is well known that the drift formation of Long Island presents a great variety of strata in comparatively short distances. Within a few hundred feet on either side of this foundation, there is no bottom so to speak, and piles are driven a great depth into the mud, whereas in the centre of our foundation the depth was only a few feet; the existing ferry slip had been blasted out at great expense, and to drive an iron-shod pile even two feet into that material, was the work of hours.

This hard material, however, occupied only a part of the foundation which comprises an area of seventeen thousand square feet. One third of this area, towards the East, was much softer in character.

To meet the requirements of this case a

Solid Timber Foundation

Was decided upon, of sufficient thickness to act as a beam, and having the requisite mass to insure uniform settling. The importance of a uniform foundation becomes evident

when we consider the size of the tower, weighing seventy thousand tons, with a height of three hundred feet above the foundation upon which the permanent pressure is five tons per square foot.

The buoyancy of the timber moreover enables us to dispense with the use of screws, commonly employed in lowering caissons.

Again, in regard to durability, it is well-known that timber immersed in salt water is imperishable, and to protect it against sea-worms, it is merely necessary to sink it beneath the river bed. It therefore at once suggested itself to make this timber platform as much as possible a part of the

Caisson.

This has been done by making the roof of the caisson a solid mass of timber, of fifteen feet in thickness. The object and purpose of a caisson in sinking a pneumatic foundation are already too well known to require any special description, it is merely a diving bell on a vast scale.

The caisson of the Brooklyn foundation is a large inverted vessel or pan, resting bottom upward, with strong sides. Into this air is forced, under a sufficient pressure to drive out the water. Entrance is had to the large working chamber thus formed underneath, through suitable shafts and air locks. The excavated material is taken out through water shafts, open above and below, and two supply shafts send down the material subsequently needed to fill up the air chamber. A few smaller pipes are also inserted for a variety of purposes,

The dimensions of the caisson are rectangular, length one hundred and sixty-eight feet, width one hundred and two feet, height of air chamber nine feet six inches, and thickness of roof before launching, five feet. The sides form a V and are nine feet thick where they join the roof, sloping down to a round edge. The inner slope of the V has an angle of forty-five degrees. The cutting edge or shoe is formed by a semi-circular casting protected by a sheet of boiler-plate, extending up three feet on the sides.

A heavy oak sill, two feet square, rests directly on this casting. The succeeding three courses are laid lengthwise, of yellow pine. After that the alternate courses are heading courses. The whole V is thoroughly held together by drift-bolts and screw-bolts. In addition there are heavy angle irons, uniting the V to the roof. At the principal corners the courses of timber are halved into each other and strapped together.

The immediate roof is composed of five courses of twelve-inch square yellow pine sticks, laid close together, bolted sideways and vertically, and having a set of bolts running through the whole of the five courses. The outer face of the caisson has a batter inward of one foot in ten, to facilitate its descent into the ground.

To make the caisson air-tight, the seams were all thoroughly caulked for a depth of four inches inside and out. In addition, a vast sheet of tin, unbroken throughout, extends over the whole caisson, between the fourth and fifth courses, and down the four sides to the shoe. The tin on the outside is further protected by a sheathing of yellow pine. The space between the timbers was filled with hot pitch and grout. As air under a pressure of forty or fifty pounds will penetrate wood with ease, the inside of the air-chamber was coated with an air-tight varnish, made of rosin, menhaden oil, and Spanish brown. The air-tightness produced by these means has throughout proved quite satisfactory.

The yellow pine timber used in construction, came principally from Georgia and Florida. Its average weight was forty-eight pounds per cubic foot, although many sticks were so heavy as to sink in water. All bolt-holes bored into this timber have a drift one-eighth inch to insure a good hold. No bolts were used with ragged ends.

Shafts.

The water shafts, two in number, are rectangular in section, seven feet by six feet six inches, made of three-eighths inch boiler plate, properly stiffened by angle-irons, and secured to the caisson timber. These shafts are open above and

below, the lower edge extending twenty-one inches below the edge of the shoe. The water within them rises and falls with the state of the tide outside.

The material to be removed is shoved under the lower edge into the pool of water underneath, and is then taken out by the clam-shell dredge of Messrs. Morris & Cummings, of New York.

This instrument is a self-acting grapnell, possessing nearly the same functions as the human hand in picking up and discharging material. Any other arrangement for excavating, in the shape of a revolving dredge, or a sand pump, was out of the question. The air-shafts are two in number, three feet six inches in diameter, and simply extend through the timber inside of the well holes, the lock being placed on top of the timber, below the ultimate water level. At the bottom of the air-shaft is an additional door, hanging down into the chamber, and enabling us to use the whole shaft as a lock. The supply shafts or pipes, two in number, are twenty-one inches in diameter, and pass through the timber, extending two feet into the chamber below, and carried up above the water level. They have a door above and below, and an equalizing pipe. When charged with material, the compressed air is admitted, the lower door falls open, and the contents fall into the chamber.

Divisions of Air-Chamber.

It was the original intention to have made the air-chamber under the caisson one entire space, without any division into compartments, thus facilitating the excavation of material. The roof was strong enough for this arrangement. Various considerations, however, led to the abandonment of that view. Since the caisson was to be *launched* like a ship, a certain number of launching ways were required, combined with a stiff frame, from the launching way to the roof.

Again, in such a boulder soil, only a few points of the edge would be touching at once, and would have to support the whole weight above. But the chief point was the rise and fall of the tides, and their effect upon the caisson. This

rise and fall amounts in the extreme to seven feet six inches. If the inflated caisson were just barely touching at high water, it would press upon the supports with a force of four thousand tons at low water, all of which had to be met by the strength of the edges and frames, there being no side friction as yet.

The air-chamber was, therefore, divided into six rooms by five dividing frames. These frames form a heavy truss of pine posts and stringers, with side sheathing and side braces to the roof every six feet, and are proportioned according to the strains in the launching. The ends of the frames are secured to the sides of the caisson by knees.

The Launch.

It was concluded to limit the pressure of the caisson during the launch to two-and-a-half tons per square foot of launching surface. This required seven ways in all, two under the edges and five under the frames. The total launching weight was 3,000 tons, comprising 111,000 cubic feet of timber, and 250 tons of iron.

The launch was arranged sideways, that is, with the long face of one hundred and sixty-eight by fourteen feet six inches high towards the water. The groundways were laid at an angle of one inch per foot, the caisson standing fifty feet back from the end of the ways. In order to buoy up the forward end of the structure, as it entered the water, and thus prevent its entire immersion, a temporary water-tight compartment was put in, one-third of the whole width. It served its purpose admirably. A full complement of wheelbarrows, crabs, winches, and other tools, were likewise placed within for future use.

The groundways consisted of two timbers eleven inches square, bolted together sideways. They were grooved like the guide of a planer, the upper launchingway fitting them correspondingly, only the outer ways were provided with ribbands.

The great danger to be apprehended in launching so large a mass on seven ways, consisted in the liability of one end

going faster than the other, and thus wedging the caisson fast on the ways. This was obviated by the V shaped groove of the groundway, and placing the ribbands on the inside of the outer ways. In order to gain an accelerating speed, the ways were laid crowning to the extent of eighteen inches. The launchingways also extended ten feet back of the caisson and were provided with shores resting against its sides. It was desirable that the rear edge of the caisson should leave the ends of the groundways simultaneously, and not stick fast on one, a thing likely to occur, unless prevented by the above arrangement.

On the 19th of March, 1870, the haunch took place. It was a success in every respect ; as soon as the last block was split out the caisson began to move. The impetus it had acquired in the first part of its course proved sufficient to overcome the immense resistance offered by the water. The air caught inside of the air-chamber, assisted materially in buoying up during the launch. Neither the battering rams provided to start her, nor the checks to hold her back, were needed. The deck was not submerged, neither was the wave of translation in front very large.

An air-pump and boiler had been set up on deck before launching. These were at once put in motion, and in a few hours the water was all displaced from the air-chamber, the air blowing out at one corner, thus proving a satisfactory state of tightness.

When the air was afterwards allowed to escape entirely, the top of the caisson settled down within seventeen inches of the water, which happened to agree with previous calculation. When inflated, the caisson remained quite level, owing to the balancing power of the heavy timber sides of the air-chamber.

The whole of the launching arrangements, as well as the responsibility of the entire launch, rested with the builders, Messrs. Webb & Bell, who deserve the greatest praise for the successful manner in which they carried out so novel a work. They accomplished the result by simple common sense arrangements; no money was wasted upon elaborate precautions or fancied contingencies.

Preparing the Site of the Foundation.

It has been estimated that the same length of time would be required to prepare the bed for the caisson as to build it. But owing to some unforseen difficulties, possession of the ground was not obtained until January 1, 1870.

The winter had hitherto been mild and continued so, much to our advantage.

The preparation of the site consisted in establishing a rectangular basin, open towards the water side, surrounded on three sides by a wall of sheet piling with the bottom levelled off to a uniform depth of eighteen feet below high water. This point was determined upon because one portion of the bottom was already as deep, and because the caisson required that much water to come in at all stages of the tide.

The dismantling of this space—the ferry slip—drawing a hundred piles, tearing out three hundred and fifty feet of fender sheathing, removing the same amount of heavy cribbing filled with stone, and dredging off the loose material on top, required in all about one month.

The dredging was performed by the Osgood dredge, and the piles drawn by a craneboat. One-half of the pier separating the Fulton Ferry slip from our inclosure was also removed without interfering with the Ferry.

All the timber and piles taken out were found to be infested with thousands of sea worms; their ravages, however, were bound to be confined to the space between low water and the mud line. A pile which was sixteen inches diameter below the mud perfectly sound and free from worms, would be found eaten away to a thin stem of three inches just above; all timber, moreover, being affected alike.

This experience shows the necessity of going below the river bed with the timber foundation, and also proves its entire safety in that position.

Dredging and Blasting.

In all there were ten thousand seven hundred yards taken out—the bulk of it in the course of a month—comprising the filling in and surface mud. A line of soundings then taken

showed three thousand yards yet to be removed before the level of eighteen feet was reached.

The character of this material was next to solid rock, as none of the dredges could make the slightest impression on it ; neither the Osgood nor the powerful grapnel of Morris & Cummings. All the old harbor charts indicated this point to be a reef of rocks or boulders, subsequently covered by filling from the shore.

Under these circumstances, recourse was necessarily had to powder. Surface blasting was not resorted to because the locality forbade the use of heavy charges, which are essential for success. A surface charge of less than three hundred pounds would have been of no effect at all.

It was determined to make holes in the bottom of four or five feet in depth, by means of a six-inch iron pile, driven in and then withdrawn. Into these holes a cannister containing twenty pounds of powder was inserted by a driver, the pile-driver was then withdrawn, and the charge exploded by electricity. The result was, a small crater and the loosening of the contiguous boulders. Three such piles were used, twenty-two feet long, and shod with iron at point and head.

Two pile drivers were coupled together for this work, and a double gang of laborers employed day and night, under charge of Captain Scott. A week's practice reduced the matter to a system, and developed the kind of cannister to be used, the exploders and the battery. From the ordinary tin cannister we passed to lapwelded tubes, cut in lengths of two feet, and plugged at each end. They proved very effective, but the supply getting scarce, recourse was had to cast-iron shells, with sides one-half inch thick. These possessed the additional advantage of dropping to the bottom of the hole of their own weight. The average number of blasts made with one gang was thirty-five; the greatest delay, however, was experienced in withdrawing the iron piles from the ground, which frequently resisted the united efforts of two sets of triple blocks, worked by two engines.

The battery used was a small frictional machine, enclosed in a light rubber case, and supplied by the Oriental Co. of

Boston, who also furnished the exploders. This machine was instantaneous in its effects, never out of order, and would set off any number of charges at the same time.

After a thorough blasting, the Osgood dredge could work to advantage for a time. Boulders, too heavy for the dredge, were slung under water by divers, and either raised or floated under water beyond the enclosure. The whole process was expensive but effective.

Nature of Bottom.

This driving of iron piles afforded a thorough knowledge of the entire ground. On the eastern side a few blows would force the pile through soft clay to a depth of forty feet, where it was brought up by a hard stratum. In the centre, however, there was a broad ridge of hard pan of varrying thickness and so hard that frequently one hundred blows of a one thousand five hundred pound hammer were required to drive the pile three feet into the material. Towards the south side, the clay again disappeared, giving place to large boulders, packed close together, a coarse sand filling up the spaces. On the water side, all sand or clay was washed away, leaving the bare stone.

As time passed along, all work was confined to the line of frames and edges alone, leaving the ridges between to be removed afterwards from under the caisson. Three-fourths of the boulders removed were of Trap, with a few of Gneiss and sandstone.

No dredge ever built is adapted for such work. Ordinary dredge buckets present too much surface for penetration, and for similar work should be replaced by a single tooth, so made as to plow up the material. This was tried with some success.

The cost of dredging the soft material on top was sixty cents per yard; but of the hard material below, including blasting, $3.62 per yard. One thousand one hundred and seventy-three blasts were fired, consuming thirteen thousand pounds of powder.

While the dredging progressed, the enclosure proceeded,

an outer row of piles was first driven, and anchored back with timber, to resist the pressure of a bank of twenty-two feet, within this line a row of sheet piling was placed, space being allowed to tow in the caisson.

Machinery.

During April, six air-compressing machines were placed on their foundations and satisfactorily tested. They were manufactured by the Burleigh Rock Drill Co. of Fitchburg, Mass. Each engine is 20 horse power, and drives two single acting air-cylinders of fourteen inch stroke, and fifteen inch diameter. Every engine has its own boiler, and they are all so connected that the stoppage of no one boiler or engine will effect the rest.

A large condensing vessel serves to precipitate the moisture in the compressed air, and deliver dry air into the caisson. The compressed air is cooled in the air pumps themselves, by the injection of a fine spray of water into the cylinder, with every stroke of the pump.

A ten inch main, one hundred and fifty feet in length, leads the air underground to the caisson, where its branches, and two rubber hose of six inches diameter, lead the air to the supply shafts, and thus into the caisson. Self-acting clack valves prevent escape of air in case of accident to the hose, which, however, had all been tested to a pressure of sixty pounds.

The double steam engines were set up on the land side to operate the dredge buckets in the water-shafts, and two engines at each end of the caisson for operating the stone sitting machinery.

Towing the Caisson into position.

By May first, the leveling off of the site had proceeded far enough to bring the caisson down from Greenpoint, a distance of five miles. Advantage had been taken of the delay to put on two more timber courses and also to make a contract with the builders to finish the remaining ten additional courses of yellow pine.

The caisson was towed down by six tugboats, under charge of Captain Maginn. During the trip the air-pump was kept in operation and the air-chamber fully inflated, so that the air-rushed out under one corner. The great buoyancy possessed by the V-shaped sides prevented any tilting. This inflation was essential, as in one part of the river there was but a foot of space between the bottom and the lower edge of the caisson.

The trip was made in two stages, on account of the tides. On the second day the caisson was warped into place without any trouble, and immediately secured by a roll of piling in front, which served to support a track for stone cars.

By the twentieth of June the ten courses of timber were laid. They cross each other at right angles, with spaces of four to five inches between the sticks. At every intersection the stick is fastened by a seven-eighth inch drift-bolt. The whole mass is thus bound together into one unyielding platform. The amount of timber laid in five weeks amounted to over one hundred thousand cubic feet. The spaces between are filled in with concrete, which serves to add to the necessary weight, as well as to harden and preserve the timber.

As the courses were built up, the outer ends were stepped back, and covered with concrete, forming a mass five feet in thickness, serving to protect it against worms.

Additional sections of water-shafts and air-shafts were put on, and an air communication established through the supply pipes.

The air-locks are seven feet high, and six feet six inches diameter inside. The sides are of half-inch boiler plate, and heads of cast-iron: six bull's eyes light up the interior. To avoid the lengthening out of the air-shafts, the locks are placed on top of the timber within water-tight compartments, which occupy the spaces of the well-holes in the towers, and will keep out the water when the timber is submerged. The

MASONRY

Is laid by means of three large dericks with horizontal

booms, standing on the caisson itself, and guyed from the land. They control all parts of the foundation.

For the lower courses, the Kingston limestone was used, furnished by Noon & Madden. These stone have both beds cut, but the sides and builds left rough with vertical quarry joints. The beds are exceptionally wide. As the base of the masonry resting on the timber is very much larger than the section of masonry at the water level, it is considered that this class of work is equally as good, and certainly far cheaper than regular dimension stone. All the stone in a course are cut to a uniform rise. The latter varying from two feet to two feet four inches.

Above low water, granite is used exclusively for face-stone.

In connection with the masonry, a large stone-yard has been established, three miles below the bridge, provided with fourteen derricks for piling up stone, and three double steam engines for unloading. The yard has a capacity of fifteen thousand yards. As the stones arrive from the quarries in sailing vessels or barges, they are unloaded and assorted in courses, and then reloaded upon stone scows, of which seven have been built, and sent to the tower. The cutting is all done at the quarries.

Work in the Air-Chamber.

On the 10th of May, 1870, the air-chamber was first entered and explored. By degrees, as the masonry was put on, and the caisson settled more, the force of workmen was increased.

The removal of the temporary wooden compartment, as well as pushing all loose material out under the edges, and cutting door-ways through the main division frames was accomplished in due time.

Several weeks were occupied in removing trap boulders which happened to come under the frames and edges. The removal of such stone from under the edge, imbedded as they were in clay, and containing often one hundred cubic

feet in mass, was a matter of difficulty and patience, enhanced moreover by a deposit of two feet of slimy dock mud.

During this period we had to contend with the rising of the caisson at every high tide, and its resting on the ground again at low water. This required the inside work to be done at low tide, when the air-chamber was comparatively free from water. Some time, therefore, elapsed before the cutting edge was sufficiently imbedded in the hard ground to shut off direct communication with the water outside. Moreover, since the shape of the shoe is rounding, it allows the air to blow out before the water inside has reached its lowest limit; this is caused by any trifling agitation of the level of the water inside, which gives the escaping air a chance to establish an outgoing current before the head of water inside becomes great enough to overcome it.

In proportion as weight was placed on top of the caisson, without any corresponding sinking of the structure, the center of gravity was raised and a condition of unstable equilibrium established. One end of the caisson would remain on the ground, while the other alone would rise with the tide, the level of the water inside being of course governed by the higher edge of the chamber.

This circumstance was attended by another phenomenon of imposing appearance. The rising of the end would not be gradual, but amount suddenly to six inches or more. The result is that for a few minutes the tension of the air inside exceeds the head of water inside, and a tremendous outward rush of air takes place under the shoe, carrying with it a huge column of water to a height of sixty feet at times. This continues until the return wave inside the caisson checks it. Such blow-offs are not felt to any extent by the men inside, beyond the warning noise and momentary draft created.

The magazine of force contained in one hundred and seventy thousand cubic feet of air, is so large that the loss of a few hundred tons of it is a trifle.

Excavation of Material.

Three courses of masonry were sufficient to prevent any further rise from the effects of the tide. By this time the force of men had been increased to over one hundred, and work could be carried on continuously.

Although the preliminary dredging had arrived at a uniform level of eighteen feet below high tide, there had been enough boulders overlooked to reduce this to sixteen and one-half feet. Several weeks were occupied in removing boulders and reducing the level to eighteen feet, before the excavating machinery was ready. In the pits under the water shafts were several large boulders, below the inner water level, upon which the lower edge of the shafts rested. These were a source of considerable anxiety, until removed by the tedious process of chipping them to pieces with long steel bars.

The material now became sufficiently exposed to enable us to arrive at the conclusion that it was of a very formidable nature, and could only be removed by slow, tedious, and persistent efforts. This had indeed been the expectation, from our previous experience in the dredging and blasting under water. But the work being under water, and therefore out of sight, did not impress us so much at the time, as now when we were face to face with it.

Nature of Material.

In the two middle chambers of the caisson the ground was composed of trap boulders, large and small packed together so closely as to touch, the space between being filled by a natural concrete, composed of decomposed fragments of green serpentine rock. The boulders were coated with this natural cement, which adhered so strongly as to defy the action of steel wedges. A steel pointed pick had no effect whatever. It was only by using a steel pointed crowbar, and driving it in the crevices with heavy sledges, that any of this material could be piled up and removed. In chambers No. one and two adjoining the Fulton ferry slips the boulders were equally as large and as numerous, but the

cementing material was clay and gravel, not as hard as the serpentine concrete. In chamber Nos. five and six, however, this hard ridge rapidly fell away, giving place to several feet of mud, underlaid by a stratum of unctuous blue clay, and continuing soft in the north corner of No. six chamber, for a depth of forty feet as had been indicated by previous soundings.

It was evident, therefore, in order to have a uniform foundation over the entire area of the caisson, it would be necessary to go down fully forty feet, and this depth was extended to forty-five feet, so as to have the timber entirely below the river bed.

The area of the caisson, seventeen thousand square feet, is so large that no uniform stratum over the whole surface would be likely to be found anywhere within this drift formation at any moderate depth below the water level. No better foundation could have been wished for than that found in chambers Nos. three and four provided it had extended all over.

Nine-tenths of the boulders were trap, transported hither during the drift period from the Palisades of the Hudson. Owing to their hardness they had resisted the wear of time the longest. They occured of all sizes, from one cubic foot up to two hundred and fifty. Boulders of quartz and gneiss rock occurred more rarely. Two large boulders of red sandstone were also found. The softer varieties of rocks had all been worn out to pebbles. A collection made of the various specimens encountered during the descent of the caisson presents a complete series of the rocks found for a hundred miles to the north and northeast of Brooklyn.

Lowering the Caisson.

The adoption of a regular system for lowering the caisson uniformly was a matter of much experiment at the beginning. No amount of pressure could force the bearing surfaces of it through the ground without crushing the cast-iron shoe at the cutting edge, or mashing the bearing frames. A few days' experience demonstrated that fact. On the contrary.

it became a matter of primary importance to dislodge all boulders in advance, before the shoe or the frames came to a bearing upon them.

All this work had to be done under water, because there was usually along the shoe a trench filled with water communicated with the water outside, and this trench was connected with cross-trenches under the frames, which in time supplied the large pools around the water shafts.

The finding of these boulders in advance was a laborious, disagreeable, never-ending task. Its performance fell entirely upon the engineering staff in the caisson, Col. Paine and Mr. Clark. The perimeter of the shoe or cutting edge measures about five hundred and forty feet, adding to this the five frames of one hundred and two feet each, gives a total length of one thousand and fifty lineal feet of bearing surface, every inch of which had to be carefully probed under water twice a day with a steel sounding bar, and the proper conclusions drawn as to the best means of moving the rocks, hard-pan, and other material found. Each shifting gang of laborers had to be informed anew whenever their turn of work came on. Being under water, this beside became a matter of memory and not of mere eyesight. Moreover, a settling of the caisson of six inches or a foot, would bring to light an entirely fresh crop of boulders in new positions, and very often half without and half within the caisson.

The shoe being of necessity unsupported, it was left for the frames to support so much of the weight of the caisson as was not balanced by the air-pressure.

The first attempt in the operation of lowering was to leave small pillars of earth under the frames, about three feet square, and from six to eight feet apart, the intervening earth being taken away, and forming part of the trench. These pillars were to be then uniformly undermined, and the caisson lowered in that manner. It was soon found that the pillars usually concealed the head of a large boulder, which required their premature removal. Again, the water would wash them down, and still oftener the laborers in adjacent

chambers, not working in unison, would undermine them and destroy their effect.

The plan next adopted worked very well, and was pursued to the end. It consisted in supporting the frames every eight feet on two wooden blocks, twelve inches square and two feet long, one above the other, with four stout oak wedges interposed between the blocks and bottom of the frame. A continuous trench, two feet deep and four feet wide, was thus maintained under the frames, giving ample working room for the removal of boulders. Whenever the shoe had been cleared out for six inches in advance, these wedges were then loosened with sledge hammers, one by one, and frame by frame, until the caisson slowly settled. Then, either new blocks were put in of a smaller size alongside, or, as was usually the case, they were allowed to crush. Very often a sudden descent of the caisson would crush half the bearing blocks, until brought up by the shoe. The operation was analogous to the splitting out of blocks and wedges during the launch of a ship.

The bottoms of the frames were originally two feet wide. This width was found too great to allow of the easy removal of rocks from underneath. They were, therefore, cut down to a width of one foot. The lower ends of the frames were likewise cut loose from the side of the caisson, to allow more easy access to the point of junction. This reduction of bearing surface added materially to the risk in case of accident.

Removal of Boulders and Earth.

Boulders occurring inside of a chamber were usually left undisturbed until the caisson had sunk sufficiently to enable us to attack them above the water level. They were then split into manageable blocks by plug and feather.

Boulders under the frame presented more difficulty. The ground in which they were imbedded was cut away with steel bars as much as possible; they were then drilled under water, and a lewis inserted. The appliances for pulling them out of their beds were various. Those first in use consisted of double sets of block and tackle, aided by winches and crow-

bars, with a gang of thirty or forty men hauling at the ropes. All this force was frequently found ineffective. The strain required being usually from two to three times the weight of the stone. The cause of this lay in the air pressure which amounted not only to the fifteen pounds of atmospheric pressure but the caisson pressure in addition, the whole being effective by reason of the water tight clay in which the stone was embeded. As soon as the boulder was loosened in its bed to a slight extent, it soon followed. These hauling arrangements were replaced after a time by three of Dudgeon's Hydraulic pulling jacks, two of ten tons and one of fifteen tons capacity. This proved to be a very effective instrument. They were usually attached to heavy screw bolts let into the roof of the caisson and formed part of a chain leading to the stone. Many boulders, however, resisted the united efforts of all three jacks.

The removal of the hard earth could be effected at the beginning only by the use of steel-pointed crow-bars driven in with sledge hammers. Under water the blow of a pick has but little effect. The long handled, round pointed shovel answered best for lifting the material out of water into wheelbarrows.

After the caisson had been lowered about two feet it became possible to build dams around the trenches under the frames and bail out the water. This enabled us to see the work at hand, and materially lightened the labor attending it. These dams were shifted from trench to trench, care being taken always to leave an open trench leading to the water shaft.

The removal of the water from the trenches was accomplished partly by hand-bailing, then by air syphon pumps and steam syphon pumps, and finally by the compressed air itself, throwing it entirely outside of the caisson through pipes introduced through the timber and masonry.

To work the air syphon a complete system of one and a-half inch pipes was placed in the caisson with suitable connection. Through this pipe air was introduced under a pressure of sixty pounds, one of the main air pumps being set apart for that purpose. The pump was constructed on the principle of a Giffard injector, and as the duty required

was simply to lift the water from three to four feet it was expected to work well, but it never did. Steam was then introduced in place of extra compressed air through the same pipes. This answered the purpose admirably, draining the trenches in a short time. It afforded an ocular demonstration of the operation of a Giffard injector, since the caisson simply corresponds to the interior of a huge boiler and steam under the same tension as the caisson pressure produced the desired result. One circumstance, however, led to its early abandonment. When the pump had worked a few minutes, the temperature would rise to a hundred degrees, driving the men from that particular chamber. Recourse was then had to a simple flexible suction hose, communicating with a pipe leading out of the caisson. The end of this hose was held in the water, so that about three-fourths of it was submerged. The compressed air rushing through the remainder of the opening kept the whole column of water in motion at a rapid rate. This mode is, of course, attended with a slight loss of compressed air, but it proved far simpler to raise the water forty feet out of the caisson than four feet inside of the caisson. Soft mud and fine sand passed out readily with water.

Boulders under the Edge.

The occurrence of large boulders under the shoe proved to be the most serious obstacle to a rapid sinking of the caisson. As long as the water from without still had free communication with the air chamber, they had to be attacked under water, the most tedious part of the operation being the removal of the earth in which they were imbedded. When the stones extended more than two or three feet outside of the caisson, no attempt was made to haul them in, but they were slowly chipped to pieces, until enough had been removed to enable the edge of the caisson to clear them.

As soon as the dredges were at work, the excavated material was dumped around the outside of the caisson with a view of stopping the ready passage of water under the shoe. This was effected after a time. Then, by building a clay dam around the boulder on the inside, and filling up the adjoining

space with bags, it became possible to dig a comparatively dry pit underneath, into which it was tumbled, provided it was not large.

Several boulders occurred which delayed all settling for three or four days at a time. In order to gain time a special force of some thirty men was then organized, who worked only at boulders from eleven o'clock at night until six A.M., when the regular gangs came to work.

It may truly be said that the results of the first month's work were not very encouraging. We had a material to deal with which is difficult to remove, even under favorable circumstances, on top of the ground. The rate of descent had not averaged six inches per week, and the boulders were increasing instead of diminishing in numbers. To look forward to a rate of lowering of even one foot per week seemed hopeless.

The work inside was rendered still more disagreeable by the frequent "blows," caused by the rushing out of the compressed air under the shoe. This would continue for several minutes until a returning wave of inflowing water from some other part of the caisson would check it, leaving, however, a foot of water all over the ground for some time, until the air pressure drove it out and the occurrence repeated itself. The trenches were usually flooded thereby, and had to be pumped or bailed out incessantly. These flows were caused by change of the water level outside, due partly to passing steamboats, but principally to constant changes in the tide. The thick fog which accompanied them was always an indication that they were transpiring in some part of the caisson.

On the other hand we were gaining daily in experience. The workmen became more accustomed to the novel situation and more practiced in the particular kind of work to be done, and the heaping up of a bank of earth around the outside, led us to hope that when the caisson had sunk a few feet lower, the conditions of air pressure, and the general regimen of the caisson would become more equable, and, what was of more importance, the free access of water from without would probably be materially curtailed. These ex-

pectations were more than realized. In a short time water became as scarce as it had been plenty before.

Blasting.

When the caisson had arrived at the depth of twenty-five feet below the water-level, the boulders became so large and numerous as to compel us at last to resort to blasting.

The idea of using powder had been entertained all along, yet our imaginary fears, supported by plausible reasoning, had prevented the attempt thus far. It was supposed that the effect of the explosion would produce a violent concussion in that dense atmosphere, rupturing the ear-drums of the men. Again, the effect upon the doors and valves of the air-locks might be such as to endanger their safety.

The principal apprehensions were, however, in the direction of the water-shafts. Here were two columns of water seven feet square, and ultimately, forty-five feet high, held in a critical balance by the pressure inside, the margin of safety being an immersion of less than two feet on part of the lower edge of the shaft in the pool surrounding it. The sudden explosion might rapidly depress the level of the pool and allow the air to escape underneath, which would be fatal both to the caisson as well as the men inside. Again, as regards blasting under the shoe and partly outside of it, it was feared that the explosion might cause a vent outward, followed by a rush of air.

The result, however, justified none of these apprehensions. First, a trial was made by firing a pistol with successively heavier charges, then small charges were fired off by a fuse, and soon blasting became an established system. The good effects were at once apparent in the lowering of the caisson from twelve to eighteen inches per week in place of six inches. As many as twenty blasts were fired in one watch, the men merely stepping into an adjacent chamber to escape the flying fragments. The hard crystalline trap split more easily than the tough gneiss rock or rotten quartz boulder, The trap invariably broke into three nearly equally-sized pieces.

Great care had to be exercised in guarding against setting fire to the yellow pine roof through the flash and the burning fuse. The gas pipe was broken several times, but the flame was extinguished before damage was done. In blasting under the shoe there was danger of injuring it, but nothing serious resulted. In fact the shoe was already so badly injured as to amount to but little. The armour-plates were bent and crushed and parly torn off by jagged points of rocks, the inner casting was cracked, and in many places the whole shoe was forced in; yet no air escaped because the clay was tight outside.

One convenient way of disposing of boulders under the shoe, was to drill a hole through them, plant the charge at the bottom, and shoot them bodily into the caisson, where they were broken up at leisure. Boulders were found fourteen feet long and five feet in diameter, containing three hundred feet and more.

The powder smoke was a decided nuisance. It would fill the chambers for half an hour or more with a thick cloud, obscuring all the lights. The use of fine rifle powder ameliorated it somewhat. A sprinkling jet of water to throw it down mechanically was of little avail.

The sulphur smell was not disagreeable, simply because the sense of smell is almost entirely lost in compressed air. This is a wise provision of nature, because foul odors certainly have their home in a caisson.

The use of powder has proved so efficient that no difficulty is expected in leveling off the irregular surface of gneiss rock upon which the New York caisson will rest.

In order to expedite the laborious task of hand drilling, a small Burleigh drill was procured, mounted on a tripod, and capable of drilling at any angle. It was operated by compressed air of sixty pounds pressure, and worked very well. The trouble, however, of placing it in position and moving it from chamber to chamber more than counterbalanced its other advantages.

As the caisson descended it left a perpendicular wall around it, the soil showing but little signs of caving in. The side moreover having an inward slope of one in ten there

was constantly an open cavity between the caisson and this perpendicular face of earth. This opening in some places was ten feet high and wide enough when a large boulder had been removed from under the shoe to allow a man to go entirely out of the caisson. Such cases were rather dangerous, since on two occasions the air had a chance to rush out above through crevices caused by slipping of earth. Such escape would then be followed by cartloads of clay and water, pouring in underneath the shoe.

The Water Shafts and Buckets.

All the material in the caisson was taken out through the water shaft by means of Morris & Cumming's "Grapnell bucket," an instrument which is analogous to the human hand in its action. It is lowered down the shaft by means of two ropes in an *open position*; arrived at the bottom it closes over the material, filling itself at the same time. It is then drawn up and emptied into a car run under for the purpose. For a cut and description I would refer to "Engineering" p. 50 vol. 7. Each bucket has a capacity of one and a half yards, a lift being accomplished every four minutes. The estimated efficiency, making all due allowances, was eight hundred yards per day. In regular harbor dredging one bucket alone will raise one thousand two hundred yards per day.

The total quantity of earth removed from the caisson was over 20,000 yards. Our buckets therefore should have removed the material quite comfortably in one month's time. In place of one month five were required, and these were five months of incessant toil and worry, everlasting breaking down and repairing, and constant study where to improve if possible. We had in fact a material which could not be dredged. The Osgood dredge which was used for leveling off before the caisson was floated in, could accomplish about ten yards a day, when not aided by submarine blasting, and the Morris & Cummings dredge fished all day without bringing up a handful.

The first disappointment lay in the fact that the buckets

would not make their own hole under the watershafts. In all other parts of the caisson the material could be properly broken up and prepared for the dredges, but the space under the shafts was inaccessible, being under water and out of sight.

When this became evident there was but one course left to overcome it. This consisted in bolting a wrought iron cap on top of the shaft and allowing the compressed air to rush into the upper part, forcing the water column down into the caisson until the shaft was empty. The pool below was then pumped out, As fast as the compressed air rushed into the shaft a quantity of stone was gradually piled up on top of the cap to prevent it from being blown off.

A large pit, with regular sloping sides, from six to eight feet in depth, was then dug out under the shaft, all boulders being lifted out and removed. This pit was dug in the dry, the surface river water being kept back by a temporary dam built around the excavation. The dirt as it is dug out was wheeled over to the other shaft. When the pit was complete it was filled with water, and the air above being gradually allowed to escape, the water would rise in the shaft until the column of balance was re-established. The stone and caps were then removed. This operation was performed quite frequently. Sometimes the shaft would run for three or four weeks without blowing out, then again only one week; but in no case could we pass below the point where it had been dug out. From one to two days were always lost in this operation. During this time the other shaft did all the work. There were in fact so many repairs to the buckets and so many other drawbacks that most of the time only one shaft was running.

The action of the bucket when it dropped on the material in the bottom of the shaft was that of puddling it into a compact hard pan, harder even than the original soil. To avoid this it was necessary for four men to be constantly stirring pool to keep the stuff alive, and even then the bottom kept rising.

A mixture of stone and clay was sure to fill up the hole in a few hours. The stone, moreover, or as apt to become so

firmly imbedded in the clay that the teeth of the bucket could not get a firm hold, it therefore became a necessity at an early day to feed all the stones by themselves and the clay by itself. The best time for feeding stone was when the shaft had been freshly dug out and they were allowed to accumulate until then. The feeding of stone required much judgment. The bucket could easily lift out any stone it could catch hold of, even up to one or two yards in size, provided the stone was shoved into the right position. Boulders could only be put in from two sides of the shaft, and one stone had to be out of the way before it became safe to put in another. The shaft being rectangular served as a guide to the bucket, compelling it to come down in the same position each time; this shape was a great advantage in one respect, but a disadvantage in another, because the square shaft is not as well adapted to withstand a bursting pressure during the operation of capping without a dangerous change of form which had to be met by external bracing. Whenever the hole under the shaft was pretty well filled up, the water in the pool was allowed to sink to within six inches of the lower edge, and attempts were made to cut down the puddled material with steel bars and sledges. A powerful stream of water from a hose was found useful in cutting it away. Often, when a stone got into a wrong position, men would dive under the shaft to loosen it. When the lungs are filled with compressed air a person can remain under water from three to four minutes with ease.

The buckets were provided with heavy teeth, seven inches long, rivetted fast to steel cutting edges, six by one. Many patterns of teeth were made before the most advantageous form was arrived at. A tooth which answers well for scooping up mud, will not last a day for grappling stones. A supply of five buckets was required to keep two in working order. The buckets very rarely became directly jammed in the shafts, except when the latter had been freshly dug out, and the hole below was deep; the buckets were then apt to catch under the edge, causing vexatious delays at times; and unless soon removed, they would then be imbedded in a deposit of clay settling down from the water in the shaft.

This had to be removed by a hose and constant bailing. When the shaft was forty-five feet high the water in it held seven feet of clay in suspension, and the columns of water, in place of being forty-five feet high, corresponding to a pressure of twenty pounds per square inch, would have a height of only thirty feet, showing that the mixture weighed some ninety pounds per cubic foot in place of sixty-three pounds. When the shaft was idle for a short time. this mixture would settle at the bottom and outside of it; at the same time the lightened water column would rise, requiring a fresh supply below. Constant attention was required not to let the water supply get too low. The dredges themselves were a fruitful source of water waste. When they closed tight, which was seldom the case, they would usually bring up two-thirds water and one-third mud, the water being allowed to drain through openings made in the bucket. But the smallest stone coming between the jaws, or any distortion of the bucket caused by dropping it down on stones, making the teeth interfere, would prevent their closing, and produce a considerable washing out of the material, as the bucket was drawn up through the water. This was the principal disadvantage attending their use. And yet, with all our drawbacks, our daily experience confirmed us in the assurance that we had selected the only instrument capable of disposing of all the material at hand, no matter how large or ill-shaped, or badly-packed the boulder; no matter how tenacious the clay and hardpan, nor how flowing the occasional veins of quicksand.

There was, indeed, one period when we were almost tempted to throw the buckets overboard, and another method was devised to take out the material. This consisted in connecting with the pit under the water shaft a wide and deep trench leading into the chamber. In the bottom of this was a track with a car on it, arranged with ropes for hauling it in and out from under the shaft. On this car was an open box lowered down from above, when the car was hauled to one side the box would be filled, then hauled back and hoisted, the hoisting ropes remaining attached to it all the time. This whole operation would have to take place

under water and out of sight. The plan never was carried out. It might, perhaps, have failed from the covering of the track by sediment.

Dumping Cars.

Two kinds of dumping cars were used. One style being provided with a turn-table for dumping the load at any point. The other and preferable kind dumped on rockers and required less attendance.

The cars were hauled back and forth by steam power. Part of the dirt was used to fill a vacant slip at the rear of the caisson. The bulk of the stone was saved and used subsequently for filling up the air chamber. The remainder of the material was dumped directly into the river and re-dredged by an Osgood dredge, this plan being found cheaper and more expeditious than direct dumping into boats. The cars several times fell into the shafts but were easily picked out by the dredges.

Management of Air Pressure.

Air was supplied from six double air pumps, located three hundred feet from caisson, a ten inch cast iron main leading therefrom ; two rubber hose of six inches diameter introduced it directly into the caisson. When any lengthening out of the shafts had to be done, the air entered only by one hose, but even that was more than ample in size.

At the beginning, the air pressure was governed entirely by the tides and regulated itself according to their height. The tightness of the caisson was quite satisfactory, and it was soon found that during the falling of the tide it was practically unnecessary to run the pumps at all, the loss of head counterbalancing the leakage. But with a rising tide the pumps had to run at full speed. A declining pressure was always attended by thick fogs which lasted until the tide changed, then, the caisson would remain clear for the next six hours. These fogs were both disagreeable and detrimental to the work by the darkness they caused. They could at times be partly overcome by pumping in a large

excess of air, but not always. The fog would occasionally be confined to particular chambers while others would be clear. A slight blowing off under the shoe always caused a fog in that neighbourhood. The air space was so large, one hundred and seventy thousand cubic feet, that there was considerable latitude for variations in different parts of the caisson. Every change in the air pressure produced a rise or fall of the column in the water shaft. As the tide fell, the water filled up the pool under the shaft, and, running over it, would endanger the safety of the dam surrounding it. As the tide rose the supply in the pool was gradually exhausted and there was danger of the air blowing out underneath unless supplied artificially.

As soon as the caisson had fairly entered into the water tight and air tight stratum of clay, the tides no longer had any effect upon the air-pressure whatever. A fixed pressure was maintained according to the calculated head of water. The clay proved so tight that the pressure could easily be raised from four to five pounds higher than called for by the head of water.

This satisfactory state continued until fresh water springs were encountered. Then there was an end to regularity of air pumping. Sometimes three pumps were sufficient, then again all six pumps running at their maximum speed, could not maintain a pressure within four or five pounds of the standard, and as the pumps were overtaxed they broke down and the pressure ran down still further. A judicious banking up of the shoe below with clay afforded considerable relief, but only partial, since it had to be removed again for lowering the caisson. We thus found ourselves in the same predicament with most caisson-sinkers, not from leakage, however, but from want of water. It had been supposed that a pumping capacity of four hundred cubic feet per minute, would prove sufficient, but it did not.

There was one critical period when the pressure ran down to eleven pounds in place of twenty, where it should have stood. On the other hand when the caisson had reached its depth and the shoe was properly banked up, four pumps were ample to keep up a pressure of twenty to twenty-two

pounds. In any event three were needed to supply the necessary fresh air for one hundred and twenty men and the numerous candles and gas lights, and to prevent a rise in temperature. The thermometer stood uniformly at seventy-eight degrees day and night, winter and summer, whether the temperature outside was ninety degrees or zero.

Relation of Upward Pressure of Air to Downward Pressure of Caisson.

In the original design for the caisson, it was the intention to make the air-chamber one vast unbroken space, without dividing or supporting frames of any kind, reliance being placed upon the solid timber platform of fifteen feet thickness to transfer all strains equally from the shoe inward. To diminish the weight above, the masonry was to be built inside of a wooden cofferdam placed on top of the caisson.

This programme was quite feasible theoretically, provided the air pressure could be maintained at the proper standard without possibility of failure, and provided the caisson was sunk through a soft uniformly yielding material. The shoe and sides of the caisson were made strong enough to resist the overweight occurring at each low tide.

The requirements of launching, however, made it necessary to introduce five heavy-trussed frames to serve as launching frames; they divided the caisson into six chambers, each frame being also well braced from the sides. These frames were allowed to remain in, large openings being cut in them for passage to and fro.

Subsequent events proved the necessity not only of these frames, but of double the additional support.

Very little attention was paid to the matter of supports at first; any irregular bearing below was easily distributed by the roof, even to the extent of having entire frames unsupported at times. The wooden blocking on which the caisson was supported proved sufficiently elastic to yield without crushing to any extent.

As the caisson sank deeper much of the dirt coming out was dumped on top of it, filling up all spaces not occupied

by masonry. This was only the beginning of the overweight to be carried ultimately. Again, at very low tides, the overweight caused by them was equal to the weight of a volume of water one hundred and sixty-eight, by one hundred and two, by seven feet, amounting to three thousand seven hundred tons alone.

Blowing Out of Water Shaft.

The overweight kept slowly increasing until one Sunday morning about six A. M., the south water shaft blew out every particle of compressed air, leaving the caisson in an instant. To say that this occurrence was an accident would certainly be wrong, because not one accident in a hundred deserves the name. In this case it was simply the legitimate result of carelessness, brought about by an over confidence in supposing that matters would take care of themselves. The immediate cause of the blowing out lay in the washing away of the dam around the pool under the shaft. These dams washed away frequently at subsequent periods, but we had had our experience and our lesson, and were prepared for it. There was unfortunately no man in the caisson at the time, so that experience is lost. Eye witnesses outside state that a dense column of water, fog, mud, and stones were thrown up five hundred feet into the air, accompanied by a terrific roar and a shower of falling fragments covering the houses for squares around. This column was seen a mile off. The noise was so frightful that the whole neighborhood was stampeded and made a rush up Fulton street. Even the toll collectors at the ferry abandoned their tills. There were three men on the caisson at the time including the watchman. He reports that the current of air rushing toward the blowing water shaft was so strong as to knock him down; while down he was hit on the back with a stone and further than that he does not remember. One of the other men jumped into the river, and the third buried himself in a coal pile. It was all over in a minute. Both doors of the air lock fell open. The dry bottom was visible through the air and water shaft; not a

particle of water had entered under the shoe into the air-chamber and for the first and only time the caison could dispense with artificial illumination. As soon as possible a stream of water was passed into the shafts from above, the locks were closed and in the course of an hour the pressure was restored to fifteen pounds, corresponding to a head of thirty-one feet.

The first entry into the caisson was made with considerable misgiving, but none of our fears were realized.

The total settling that took place amouuted to ten inches in all. Every block under the frames and posts was absolutely crushed, the ground being too compact to yield ; none of the frames however were injured or out of line. The brunt of the blow was, of course, taken by the shoe and sides of the caisson. One sharp boulder in number two chamber had cut the armor plate, crushed through the shoe casting, and buried itself a foot deep into the heavy oak sill, at the same time forcing in the sides some six inches. In a number of places the sides were forced in to that amount, but in no instance were they forced outward. The marvel is that the air tightness was not impaired in the least.

The nine courses of timber forming the sides of the air chamber were permanently compressed to the extent of two inches, as was shown by protruding bolt-heads and the shearing off of a number of diagonal bolts. The lower sills of the frames were also torn where they came upon boulders.

The weight of the caisson at the time was seventeen thousand, six hundred and seventy-five tons. The air blew out so suddenly that this weight must have acted with considerable impact in falling through the space of ten inches. The bearing surface at the time was as follows ; The four edges of the caisson five hundred and fifty feet long and seven inches wide, amounting to three hundred and twenty-two square feet ; the five frames each one hundred feet long and one foot wide, resting on twelve blocks one foot wide, amounting to sixty square feet, and giving a total of three hundred and eighty two square feet to meet the above pressure. This is at the rate of forty-six tons per square foot.

But more than one-half of the shoe was undermined to a depth of one foot or more which reduced the practical bearing substance by nearly one half. At the commencement of the shock, there was therefore a pressure of eighty tons per square foot, no allowance being made for impact, which may have doubled this rate. The caisson had settled ten inches. The shoe had buried itself so as to present a width of twelve inches and through the crushing of the blocks the frames were in many places resting bodily on the ground. The settling had therefore stopped when a bearing surface of seven hundred and seventy-five square feet had been reached giving a pressure of twenty-three tons per square foot.

The ultimate pressure on the base of the caisson due to the weight of the tower and superstructure will be only five tons per square foot; hence the margin of safety against crushing is ample. All the above extreme rates of transverse crushing are within the limits of good yellow pine. The fact that the majority of the blocks did crush is attributable mainly to their irregular bearing and to their shortness, a block of four feet in length will bear a much larger pressure upon one square foot of its surface than a block of two feet in length; the same is true in regard to relative breadth. Yellow pine is essentially a heart wood, and before yielding to compression it will split out side ways away from the heart. In the roof of the caisson no effects whatever were produced by the pressure of posts. The timbers are bolted so close laterlly that no yeilding sideways can take place. Subsequent examinations showed that the roof of the air-chamber has assumed a permanent average depression of four and one-half inches, being least in the end chamber, and greatest near the water shafts, where there was the least support by frames, and where these openings had cut the timber through from top to bottom. This deflection never increased any. The amount is comparatively small when we consider that the transverse span is one hundred and two feet between bearings, that the whole caisson and timber above it is a composite structure, bolted together, and that the joints in the timber are butt joints. That amount of

deflection is scarcely sufficient to bring all the bolts to a full bearing.

Additional Shores.

As the caisson proceeded in its downward course, the disproportion between the dead weight above and the air pressure from below became greater and greater. For instance, on the 15th of November, the escape of air under the shoe was so strong that no more than ten pounds of air pressure could be maintained. The over-pressure entailed thereby was twelve thousand two hundred and forty tons. This was received by a bearing surface of two hundred and eighty square feet, causing a pressure of forty-four tons per square foot.

In order to meet this constantly increasing over-weight a large number of additional shores were introduced into the caisson. They rested upon a block and wedges, and supported a cap spiked against the roof. The presence of these shores added considerable to the labor of lowering the caisson, and diminished the available working space otherwise. They gave, however, a positive assurance against any crushing weight from above, and could moreover be easily removed when a boulder was taken out, which could not be done with the permanent frames.

The downward movement of the caisson was usually so impulsive that the blocks under the posts were allowed to crush and were subsequently dug out. In fact, their crushing was the only indication we had that any portion of the caisson was bearing particularly hard. The noise made by splitting of blocks and posts was rather ominous, and inclined to make the reflecting mind nervous in view of the impending mass of thirty thousand tons overhead.

Side Friction.

No satisfactory estimate could ever be made of side friction. There must have been some, but of a very irregular character. At times an outside boulder would apparently hold one end of the caisson until a bolt head or part of the timber gave way. The batter on the outside being one foot in ten,

was calculated to relieve the caisson from side friction. The workmen, however, never dug out far enough behind the shoe, thus causing great friction for several feet up the sides, and pressing in the sides to as much as nine inches in some places. The side friction probably never exceeded three thousand tons. The larger the base of a caisson the smaller is the percentage of side friction available to counteract downward pressure, whereas in a narrow caisson, penetrating a uniform sand, it is often sufficient to counterbalance the whole weight.

Brick Piers.

When the caisson had arrived within three feet of its proposed resting place, it was considered advisable while the air chamber was being filled with concrete, to erect for its support seventy-two brick piers. systematically located, and averaging twenty square feet of base. Their ultimate capacity was just sufficient to support the whole weight above in case the air should blow out. It was felt that where openings exist like the water shafts or supply shafts, there exists also a possibility of the air blowing out, no matter what precautions are taken, or how much care is used. The precaution was, therefore, safe, even if not needed. Subsequent events showed the necessity of it. The piers were completed in three weeks, requiring 250,000 bricks in their construction. The inevitable strike attended the employment of the large force of bricklayers, men new to the place and circumstances. It was easily overcome, however, and caused no delay.

Blowing Out of Supply Shaft.

Shortly after the caisson had come to a bearing on the piers and the concreting had been in process a fortnight, one of the supply shafts blew out. The tension of the air was reduced in a few minutes from eighteen to four pounds, and the piers had to bear the brunt of the weight.

A few words will suffice to explain the mode of operating the supply shaft. It consists of a tube forty-five feet long

and twenty-one inches diameter, inside, with the door at the bottom opening into the air-chamber, and a long door on top, through which the material is thrown in. When the upper door is open, the lower one is held shut by the air-pressure, assisted by two iron clamps worked by levers. As soon as a certain quantity of material has been thrown in, the upper door is pulled up, and the compressed air being then allowed to enter, firmly closes it. When the shaft is filled with compressed air, a signal is given to the attendant below, who removes the lugs, the door falls, and the contents of the shaft drop into the air chamber. The operation is very simple and rapid, and perfectly safe with the most ordinary precaution. Two of these shafts were found ample to furnish all the material required for filling up the caisson. They had worked well for five weeks, but danger always steps in, when through daily use and familiarity the attendants become careless and reckless. It had occurred at times that a charge of building stones or brick would become jammed, and only part of a load would drop out. To ascertain this fact, a string with a weight was let down from above each time, so as to avoid putting in a double charge. Upon this occasion a charge had jammed; the men dumped in another without measuring the depth either before or after, and then gave the signal to the man below, without shutting the upper door, or letting on the compressed air. The second charge happened to loosen the first, and the two together overcame the pressure against the lower door, when the lugs were turned. As soon as this happened, the air commenced to rush out of the caisson with a great noise, carrying up stone and gravel with it. The men above ran away, leaving those below to their fate. Any one with the least presence of mind could have closed the upper door by simply pulling at the rope.

I happened to be on the caisson at the time. The noise was so deafening that no voice could be heard. The setting free of water vapor from the rarifying air, producing a dark, impenetrable cloud of mist, and extinguished the lights. No man knew where he was going, all ran against pillars or

posts, or fell over each other in the darkness. The water rose to our knees, and we supposed, of course that the river had broken in. It was afterward ascertained that this was due to the sudden discharge of the columns of water contained in the water shafts. I was in a remote part of the caisson at the, time; half a minute elapsed before I realized what was occurring, and had groped my way to the supply shaft where the air was blowing out. Here I joined several firemen in scraping away the heaps of gravel and large stones lying under the shaft, which prevented the lower door from being closed. The size of this heap proved the fact of the double charge. From two to three minutes elapsed before we succeeded in closing the lower doors. Of course everything was all over then, and the pressure, which had run down from seventeen to four pounds, was fully restored in the course of fifteen minutes. A clear and pure atmosphere accompanied it. The effect upon the human system, and the ears, was slight, no more than is experienced in passing out of the airlock.

Careful examination was made to see what effect the weight of thirty thousand tons had upon the brick pillars and other supports. Although the pressure on the piers was twelve tons per square foot, these showed no signs of yielding. In the neighborhood of the water shafts and supply shafts, where there were no brick piers or other supports, a slight local depression took place in the roof. The occurrence demonstrated the fact that the pillars were strong enough to bear the whole load, and also proved the necessity of their erection. A few small springs of brackish and fresh water started beneath the concrete under the shoe, but was easily repressed. There was no increase of air leakage.

It was rather remarkable to notice that there was no rush of air in the immediate vicinity of the supply shaft, not even for several feet up the shaft ; the action was one of free expansion in all directions.

The question naturally arises, what would have been the result if water had entered the caisson as rapidly as the air escaped. The experience here showed that the confusion

the darkness, and other obstacles were sufficient to prevent the majority of the men from making their escape by the airlocks, no matter how ample the facilities. If the water entered as rapidly as the air escaped there would then be the same pressure of air during the whole time of escape. Now it so happens that the supply shafts project two feet below the roof into the air-chamber; as soon, therefore, as the water reaches the bottom of the shaft it will instantly rise in it, forming a column of balance and checking the further escape of air. The remaining two feet would form a breathing space sufficient for the men to live, and even if the rush of water were to reduce this space to one foot, there would be enough left to save all hands who retained sufficient presence of mind.

Filling up the Air-Chamber.

The operation of the two supply shafts has already been described. Their capacity proved ample for all requirements. Concrete was laid at the rate of one hundred yards per day of sixteen hours. As the space became more contracted, this quantity was reduced. A great saving in time as well as amount of concrete was effected by letting the edges of the caisson sink into the ground three and a half feet deeper than the average level of the bottom. This reduced the height of the air chamber from nine feet six inches to six feet, and diminished the amount to be filled in about one-third.

The concrete consisted of one part of Rosendale cement, two of sand, and four of small-sized gravel. The sand and cement were mixed above and passed through one shaft, the gravel through the other. The gravel came from the Long Island beaches, where the action of the waves had washed it absolutely clean, and sorted it in layers of uniform size. During most of the time the weather outside was so cold that the concrete had to be mixed below. At a later period it was mixed above and sent down directly. No trouble was ever experienced from its setting before it was spread out and rammed, nor did it ever set in the supply shafts; much labor can be saved thereby in the air-chamber. The gravel being

full of frost, frequently froze fast in the shafts; this was obviated by introducing a steam pipe and thawing out each charge.

The boulders which had been taken out of the caisson were broken up into square blocks, and again built in below with the concrete. The general mode pursued in the filling was, to build narrow bulkheads from three to four feet wide from the floor to the roof all around. The sides being kept vertical by boards, which were removed after concrete had hardened. Next to the roof a shallow, sloping layer was rammed in with narrow, flat-faced iron rammers. This place required careful watching as it was apt to be slighted, and yet was the most important point in all the filling. When, in making the repairs of the fire, it became necessary to cut out a considerable portion of the concrete, it was found that the part next to the roof was the most compact portion of the whole. Every layer of concrete was allowed to remain for five hours before another was put on. The total quantity required was about four thousand yards including the brick piers.

The rapid influx of fresh water springs prevented any material reduction of the air pressure. The water-shafts were cut away below and filled up with concrete, to the line of the roof. After the cavity was filled, and the air pressure taken off, it was found that sufficient water leaked through the concrete to fill the shafts to the top. They were then filled from above with concrete, lowered down in self-dumping buckets. The caps to these shafts should have been provided with small air-locks, so as to fill them in the dry. The water rising in these shafts was perfectly fresh, without a trace of salt, which shows that the timbers will be saturated with fresh water. Its temperature was remarkably high, seventy degrees, whereas, that of pure spring water is fifty-five degrees, and of the river, fifty degrees. This would indicate that the whole mass of timber and concrete must have been heated to the temperature existing in the air-chamber, which averaged from seventy to eighty degrees throughout the winter, and was even greater up in the timber, where all the hot air was

concentrated. It is also probable that the water penetrating the concrete as soon as the air-pressure ceased, would produce some heat by contact with the small quantity of free lime there existing. The concrete filling was permeated by air throughout. Even when the last charge was put in the air bubbled up under the edges of the caisson, requiring a passage of fifty feet through the concrete.

Fires.

The danger from fire in an atmosphere of compressed air is very serious, and becomes doubly so, with a wooden caisson penetrating a water tight stratum. Already at a pressure of twenty-five pounds per square inch, the flame of a candle will return when blown out, and all inflammable materials have to be carefully banished. Several minor fires at the beginning showed the necessity of caution. One was of sufficient magnitude to demand the flooding of the caisson, which was then easily accomplished, because the water entered freely under the shoe, as the air escaped through valves provided for that purpose. When therefore the fact was settled that the river water was permanently excluded from the caisson, it became a matter of primary importance to guard against fires, and accordingly two hose connections were provided, throwing streams of one and a half inches at sixty-five pounds pressure. Steam pipes were introduced, connecting with boilers outside. In addition all seams between the roof timbers were carefully pointed with cement, and iron shields provided over the permanent lights. It was made the special duty of two men to watch continually over all lights. Notwithstanding all these précautions there was a seam where the supporting frames join the roof that had not been pointed; an empty candle box was nailed under it, in which some man kept his dinner, and while getting it he probably held a candle against the roof for some time. This proved to be the heel of Achilles, a fire being discovered there on the evening of December 2. Being directly over the frame it had remained undiscovered, until the latter had been partially burnt through. From its size it is supposed to have been burning for several

hours previous. A slight stampede ensued among the men, but no one left the caisson. All appliances for putting it out were brought to bear. While the hose was getting ready, two large cylinders of carbonic acid gas under two hundred and twenty-five pounds pressure were discharged into it without producing any effect whatever. As soon as the stream was stopped the timber would reignite immediately. The two streams of water, however, soon extinguished all fire that could be seen at the time. There was a violent draft of air through the burnt aperture. This was stopped with cement, and the two streams of water were allowed to play in the hole for two hours. At the end of that time one of them was replaced by steam at ninety pounds pressure, and allowed to run for half an hour. It was impossible to ascertain whether the steam was of any benefit. It was, therefore, shortly stopped off and the water turned on again. The steam may even have aided the draft.

In the meantime the question of flooding the caisson was seriously discussed. To extinguish the fire without having recourse to this resort was very desirable, yet, on the other hand, if the fire was not out, it was simply a question of time how soon the entire structure would be destroyed.

One great objection to the flooding was the condition of the water shaft, which was capped above and resting below on some boulders. A gang of men were busy all night digging them out. The flooding would necessarily be accompanied by some settling of the caisson since it was equivalent to an extra weight of twenty-eight thousand tons, and if the water shaft came down on the boulders it might become so crippled as to impair the tightness of the caisson permanently.

The problem to be asked in the flooding was to substitute the compressed air by the water poured in through the water shafts from above, and to so regulate the escape of the air as to always maintain the same pressure against the roof of the caisson, even up to the last inch below the roof, until the water had entirely replaced the air. The supply of the former would of course be limited and variable, and if the air should be all out before the water had reached the

roof, the result would be a sudden drop of the caisson, and the destruction of all supports by the weight of twenty-eight thousand tons, besides running the risk of causing the caisson to leak so badly as to render its reinflation impossible. The situation was entirely different from that at the first fire, when the water rushed in under the edges as rapidly as the air escaped, and thus maintained a uniform pressure at all times. These various considerations unfortunately appeared of great weight at that time and under such circumstances of mental excitement and bodily prostration. It was concluded first to exhaust all other means for ascertaining whether the fire was out. This resolve was strengthened by the fact that at four A. M. the water thrown by the hose ran back through the orifice into which it was thrown, thereby leading us to think that the burnt cavity was filled with water and could hold no more.

The only way to ascertain the presence of fire was to bore for it at random through the solid timbers. A number of holes were bored up for a distance of two feet. They showed no fire. Others were then bored up for three feet, showing no fire. This result was of course encouraging. Time was lost in lengthening out augers and also in the boring, because the draft carried the chips up. At eight A. M. a hole four feet high revealed the dreaded fact that the fourth course of timber was one mass of living coals.

All available engines of the Fire Department were soon at work pouring water into the other water shaft. Additional forces were brought up by and by. The Fuller, a harbor fire boat, supplied eight powerful streams; the J. L. Tebo three, and the navy yard tug two more. By 10 A. M., thirty-eight streams of water were flowing into the caisson, beside the water from the pipes in the caisson itself.

Our water-shafts most certainly proved their value in this instance. Without them the introduction of such a quantity of water in so short a time would have been out of the question. By half-past three p. m. the air-chamber was filled. Total quantity of water required, one million three hundred and fifty thousand gallons.

The escape of air was regulated by the pressure gauges;

at times, as it escaped too rapidly, the pumps were started to restore the pressure. When the water had reached within two feet of the roof, the escape of air through the large valves was thereby cut off, and the balance escaped by leakage and through two small one and one-half inch pipes, reaching within a half-inch of the roof. During the latter stage the pressure fell at one time from nineteen to ten pounds. The settling of the caisson of two inches was probably due to that. After the flooding, the water in the shafts was kept ten feet above tide level, and remained so with very little feeding, thus showing that the earth was practically water-tight under the shoe.

The caisson remained flooded for two and one-half days. Six hours were required to force out the water again. It all ran out over the top of the water-shafts, requiring about twenty-two pounds of air pressure.

The structure proved tighter than before the flooding, owing to the swelling of the timber. An inspection below showed but little apparent damage, beyond blocks that were crushed and some posts thrown over.

The building of the brick piers was at once resumed and completed in two weeks, and the caisson lowered down on them through the remaining distance of two feet.

For several weeks subsequently the odor of turpentine and other products of the combustion of yellow pine was very strong above the caisson, being forced out with the air bubbles. They gave rise to very unpleasant suspicions, which were happily dissipated by time.

A large quantity of frothy pyrolignic acid also made its appearance on top of the masonry, showing that a destructive distillation of wood had been going on. This continued for over three months, as long as any air remained below.

Extent of Fire, and Repairs.

About two hundred borings were made in the roof of the caisson for the purpose of ascertaining the extent of the fire, both laterally as well as vertically. It was found that it was confined to the third and fourth courses of timber, but had

spread out laterally in many different directions, covering a much larger area than was anticipated, the remotest points being some fifty feet apart. The fact of the air rushing out through every bore hole seemed to show that we had to depend upon the immediate roof for retaining the compressed air. Hence the first conclusion arrived at in regard to making the repairs was to wait until the air-chamber had been partly filled in around the edges, then let off the air pressure entirely, trusting to the pillars and concrete to support the weight, and whatever spring water came in was to be pumped out. Large holes could then be cut in the roof and the repairs made, provided that the waters did not come in too fast through the timbers. It was very desirable, however, to gain time and do as much as possible at once, while the air-pressure was yet on. This made it necessary to check in some way the loss of air attending the cutting away of the timber.

With this object in view it appeared advisable to inject cement into the burnt cavities through the bore holes until the leakage was stopped. Accordingly a cylinder was prepared with a piston and a one and a quarter inch injecting pipe, and when freshly filled was placed under a hole, and the cement forced up by a screw jack. This worked well. Experiments showed that a mixture of one part of cement and one of sand could be forced a distance of ten feet through a small pipe and then would spread out laterally to some distance. As soon, however, as a certain moderate amount of resistance was experienced, all the water would be squeezed out, and it became impossible to force the charge another inch. We soon found that the mere suction of air through the blow holes was sufficient to draw up the cement loosely through a pipe. When a hole was clogged the stuffer was applied to compact it. By these means six hundred cubic feet of cement were injected, and all escape of air ceased. A number of trial bore holes failed to disclose any space not filled with hard cement. We already flattered ourselves that this filling might answer every purpose, but in order to make sure, one large hole, six feet

square, was cut up into the roof through a length of five courses, directly over the place where the fire had originated. Here we found that the cement had indeed filled all vacant spaces, but that the timber was covered with a layer of soft and brittle charcoal, varying from one to three inches in thickness.

There was no other alternative now but to go to work and cut in a sufficient number of openings, remove all the injected cement, and carefully scrape the charcoal from every burnt stick of timber. This task required eighteen carpenters, day and night, for two months, beside the attendance of common labor, and delayed the filling up of the air chamber by fully four weeks. The work was extremely disagreeable and unhealthy; men had to lie for hours in confined spots, without room to turn, and breathing a foul mixture of hot candle-smoke and cement-dust combined with powdered charcoal, and under pressure at that, the temperature being eighty degrees. In proportion as the cement was cut away, the full extent of the fire gradually began to dawn upon us. In place of one opening in the timber five were required in order to reach the remotest points. They varied from three to four feet square in size.

Above the first opening the fire had destroyed the third, fourth, and fifth course, having burned through the tin which lies between the fourth and fifth, and also one or two cubic feet of the sixth course. In this latter course the timbers are laid three inches apart with concrete between. This concrete checked all further spread of the fire in the sixth course, and in every other spot, except above the large opening, the tin had acted as an effective barrier. The fourth course under the tin was the principal sufferer. The various ramifications of the fire had evidently been caused by air leaks. In several places one stick was burned away for thirty feet, and the adjoining ones remained sound. The fattest sticks had succumbed the soonest. Since the timber was laid in courses at right angles, there was an opportunity for the fire to branch off in a zigzag direction, leaving one stick and passing off in another course to the right or left and up or down. The general combustion, however, was of the nature of a

slow charring, progressing equally in all directions. Whenever a stick was only partially consumed it was carefully scraped and the cavity rammed full of cement. The larger spaces were filled up with yellow pine forced in with screw-jacks and wedges, in lengths of from eight to ten feet, and well-bolted vertically and laterally. Care was taken to break joints and to scarf as much as possible. It was difficult to introduce larger timber, since it had to be inserted into the fourth course through the openings cut from below. All jagged burnt ends were cut to a square face with chisels. After everything was filled up solid, a number of five-foot bolts were driven up from below so as to unite both the old and new timber into a compact body.

Forty iron straps of 4x3-4 iron were also bolted against the roof from below, so as to balance the break of bond in the fourth course. In order to further prevent any undue settling over the line of the fire, the space beneath in the air-chamber was built entirely of square blocks of trap-rock, carefully laid in cement, in place of the gravel concrete which fills the rest of the chamber. It must be remembered that there are still eleven courses of sound timber above the burnt district. These have abundant capacity to distribute any local deficiency in equal bearing. From the faithful manner in which the work was done it is certain that the burnt district is fully as strong, if not stronger than the rest of the caisson.

The final repairs were concluded March 6th, and the air chamber completely filled March 11th.

Lighting of Caisson.

The subject of illuminating a caisson in a satisfactory manner, is rather a difficult problem to solve. A powerful light is of prime necessity, to overcome the want of all reflecting surfaces; to penetrate the thick mist usually occupying such places; and to illuminate every foot of soil which was anything but uniform in character. The burning of candles is attended with an intolerable amount of smoke, resulting from a rapid but incomplete combustion. This nuisance was overcome somewhat by reducing the size of the wick, and of the

candle, and by mixing alum with the tallow, and also steeping the wick in vinegar. The inhaling of so much floating carbon is very injurious to the lungs, as the lamp-black remains in them for weeks and months. Nevertheless candles had to be used more or less for all special work requiring illumination close by. Lamps are of little account since they smoke more than candles, and the oil is dangerous in case of fire.

Fortunately, the existence of an establishment in New York, for the production of oxygen gas in large quantities, and at moderate prices, made the introduction of calcium lights quite feasible.

For a time, cylinders filled with compressed oxygen gas, and compressed coal gas, were lowered into the caisson and there used. The danger, however, of breaking a freshly charged cylinder was too great on account of the risk of an explosion. A double system of pipes was therefore put up in the air-chamber, one for oxygen and the other for coal gas, which takes the place of pure hydrogen. In the end of each chamber was one burner, and a special one next to the water shafts, making fourteen calcium lights in all. In addition, there were sixty burners for common street gas, which was used whenever the supply of oxygen failed. The two gas-mains passed to the outside of the caisson, where they connected with two tanks. In order to make the system effective it was necessary to have the gas pressure always one pound, or thereabouts, in excess of the air pressure in the caisson, and also, to maintain this as the caisson sank. For this purpose the two gas tanks were filled with water from an artificial reservoir, having a head always slighly in excess of the caisson pressure. Into these tanks the gases were discharged from smaller cylinders, under a pressure of two hundred and twenty-five pounds. The immediate effect was to force the water from them back into the reservoir, until the tank was full, when the supply was stopped. The pipes leading to the caisson remained open, and the gas passed through them under the pressure due to the artificial head of water. By means of glass gauges the contents of the tanks could be watched and replenished as often as necessary. As the cais-

son sank, the reservoir was raised from time to time. This was rather troublesome, and was avoided in the New York caisson by placing the gas tank below in the air-chamber, otherwise a tower of eighty feet in height, would have to be built by degrees. The gases could, of course, have been pumped directly into the tanks, were it not that the stroke of the pump creates an unpleasant jumping of the flame. The oxygen gas was delivered in a compressed state, and the coal gas was compressed on the spot. When the oxygen gas was of good quality, two calcium lights were sufficient for one chamber, one hundred and two feet long by thirty feet wide. The heat produced is less than that of a gas flame, and the product of combustion water. One attendant was sufficient for fourteen lights, besides all the gas lights. The lime-ball requires occasional turning, as it wears away by the action of the flame, and also requires frequent renewal when water condenses in the pipes. The blow-pipe burners are apt to burn out and get out of order. The explosive flame will also run back and melt the rubber connection. In short, quite an apprenticeship is necessary to adapt the calcium lights to all the new conditions. The only danger lies in leakage of pipes and from carelessness in leaving cocks open. One gas explosion took place below, sufficient to singe off whiskers and create some alarm. The sense of smell is so blunted that the leakage of coal gas is not easily detected. But the ordinary gas lights were found to be the most economical. Their cost is only one-fifth of the calcium light, and about one-third of candles. They give all the light that is needed, and can easily be located at all points. They produce, however, an intolerable amount of heat, and vitiate the air more than candles, although producing but little visible carbon. The gas-burners kept the temperature below at eighty degrees to eighty-five degrees. As long as the air-pressure was so irregular, all lights required careful attention and regulating. During winter, the water-pipes above, and the reservoir, were kept from freezing by steam-pipes laid alongside.

The cost of candles, calcium lights, and gas, was about five thousand dollars, of which candles cost more than one-

half; not including the necessary apparatus, which in one item alone comprised over forty gas cylinders.

Organization of Working Force.

Each shift of men worked in the caisson eight hours at a time, the first watch from six A. M. to three P. M., including one hour for breakfast ; the next watch from three P. M. to eleven P. M., including one hour for supper ; then a special night-gang from eleven P. M. to six A. M.

The majority of the men took their meals along and remained down the full eight hours without any injury.

The two day-shifts alternated from week to week. They consisted of one general foreman, six assistant foremen (one for each chamber), and one hundred and twelve laborers. The special night-gang was composed of one general foreman, with two assistants and forty laborers, making a total force below of three general foremen, fourteen assistants, and two hundred and sixty-four laborers. This force was constantly recruited from time to time, and an inspection of the time books shows that two thousand five hundred different men have worked in the caisson.

On deck there were double shifts of engineers and firemen to run the excavating engines, and engines for running the dirt-cars, also two gangs for attending to the dumping of the latter. In addition there were the engineers for the air-compressors and stone-hoisting engine, blacksmiths, machinists, and gas men, one gang to remove the boulders brought up by the buckets. A carpenter's force of twenty-five men and thirty men for setting masonry.

The total daily force amounted in all to three hundred and sixty men.

Under ordinary circumstances it would have been economical to work three full gangs below throughout the twenty-four hours. The work, however, was so severe upon the dredge buckets that the night hours from twelve to six A. M. were devoted to repairs, both to the buckets as well as cars, engines and other machinery. The night gang usually devoted themselves to getting out boulders where

only a few men could work, or they would run one shaft alone or be digging out the other one.

Two shanties were put up provided with duly numbered hooks and pegs for the men's clothes, most of which were left above, the temperature below being too warm. Rubber boots were furnished by the company at cost price. In front of the houses are sets of wash-troughs with hot and cold water.

As each air lock held thirty men, two sets of lockings were required to let down one hundred and twenty. The old gang remained until relieved by the new.

No trouble was experienced in getting all the labor required, when one man left a dozen were ready to take his place ; New York in fact is the best labor market in the country. There was one small strike at the beginning, but it amounted to nothing. The wages paid at first were two dollars per day for eight hours' work. After the caisson had reached the depth of twenty-eight feet the rate was increased to two dollars and twenty-five cents for eight hours' work and remained at that up to the end. The earlier stages of the work were in reality far more disagreeable than at the end ; on account of the constant fog and influx of water, whereas in the latter stages the work was dry.

Effect of Compressed Air and Other Causes Upon Health.

The depth reached by this caisson was not sufficient to produce such fatal cases of paralysis as attended the sinking of the deeper caissons at St. Louis. Only six men were temporarily paralysed, and in each case upon their first visit, and after remaining but a short period of time. None of the old hands were effected to any extent, even when remaining down eight hours.

Inasmuch as the medical profession are as yet somewhat undecided in their explanations of the real cause of paralysis in compressed air, it was proposed in the deeper New York caisson to follow the course pointed out by Captain Eads,

of shortening the hours of labor from time to time as the case may demand it, and thus reduce the period that the human system is in contact with the exciting cause. It is not probable that paralysis is due to the direct pressure of compressed air, otherwise all men would be immediately affected alike, without exception, as all parts of the body must be absolutely permeable. The cause may perhaps be sought for in the fact that with each breath a quantity of oxygen is inhaled from two to three times greater than that inhaled in a normal atmosphere. That the system struggles against this abnormal state of affairs is shown by the fact that the number of inhalations per minute is involuntarily reduced from thirty to fifty per cent. It follows, therefore, that the shorter the period of exposure to compressed air the less the risk.

On the other hand, persons affected immediately upon emerging are usually somewhat nervous and excited, which incites excessive action of the heart, and thus accelerates the general tendency to paralysis. Violent exertion, such as climbing of ladders and hard work, must be avoided.

The only other inconvenience experienced in caisson work is in the temporary effect on the ears in passing through the air lock. A short practice, however, soon enlarges the eustachian tubes, so that by setting the jaws at a certain angle no effect whatever is felt on the ear drum.

As the weather became colder the men became subject to cold and congestion of the lungs while undergoing the severe change of the temperature from eighty degrees to forty degrees, which attends a passage out of the air lock. A simple and effective remedy was provided for this by putting in a steam coil composed of six rings of one inch pipe, lining the inside of the lock and provided with an outlet pipe. As soon as the outlet air cocks were opened, steam was allowed to flow through the coil with the most satisfactory results. No reduction whatever of temperature took place, neither was there any formation of the disagreeable mist which otherwise attends a reduction of pressure.

Another sanitary measure, rendered necessary by the

presence of so large a number of men in a confined space, was the provision of a water closet so arranged as to discharge its contents out into the open air. That some care had to be exercised in its use will be self-evident to caisson men.

MASONRY.

Eleven courses of masonry were laid, averaging from twenty-four to twenty-eight inches high. Each course contained from seven hundred to eight hundred cubic yards and the size of the stone varied from thirty to one hundred cubic feet. The masonry of the first seven courses was composed of rough blocks, all bedded to an uniform rise. The blocks were all rectangular in shape, with the vertical faces trimmed down so as not to exceed joints four inches wide when laid in the wall. The Kingston limestone was used alone for these courses. They were set in heavy beds of cement, and all the spaces filled in with cement or with concrete, when the spaces were large enough to admit of the latter. As the low water line was approached granite was substituted on the face in place of limestone, the latter being continued for backing.

Where the backing is all cut and composed of large blocks, such masonry can be laid quite rapidly. One whole course has been laid per week, notwithstanding the drawbacks caused by the mud and water from the dredges, and at no time was the masonry behind the excavation in point of progress. On the 10th of December the level of the masonry had arrived at ordinary high water level, and was then suspended for the season by the severity of the weather. The granite was furnished by Bodwell & Webster, from the Island quarries in Penobscot Bay, on the coast of Maine. When the regular masonry was laid off it was found that the caisson had moved one foot toward the river and nine inches toward the ferry.

The stone-setting machinery consisted of three boom derricks standing on the masonry with masts fifty-five feet high and thirty-five feet horizontal booms. They controlled all points of the stone-work. The guys were secured outside

and had to be regulated from time to time. In the New York caisson the derrick guys are fastened directly to the caisson itself. The same derricks will be used to carry up the tower masonry for about fifty feet, when they will be replaced by balance derricks.

The stones were raised by two engines, each working three drums, controlled by friction gearing. They have given perfect satisfaction, the stones being handled with ease and rapidity, and under complete control in setting.

DOCK.

During the winter months, the substantial dock resting on top of the caisson, on the river side, was completed, filled in, and provided with a track, turn-tables, and unloading derrick.

On the land side the excavation has been filled in level up to the masonry.

When the caisson proper had been filled in the locks were removed, the water-shaft filled, and the sections above the timber taken out. Next, the coffer dams inside the masonry well-holes were removed and the mud dug out. No water leaked through the masonry, but considerable fresh spring water oozed up through the timber foundation, that was easily kept in check by pumps. These well-holes were filled with concrete for a height of twenty-five feet, requiring five hundred and fifty cubic yards. For the remainder of the distance, up to the floor line, these well-holes remain open, so as to save masonry.

General Dimensions Brooklyn Caisson.

Length over all	168	feet.
Breadth	102	,,
Height of air chamber	$9\frac{1}{2}$	,,
Total height when launched,	$14\frac{1}{2}$	,,
" " when completed	$21\frac{1}{2}$	,,
Cubic feet of timber in it	111,000	,,
Weight of iron work	250	tons.
Launching weight of caisson	3,000	,,

THE NEW YORK FOUNDATION.

The foundation of the New York tower is located at the end of pier twenty-nine, in deep water, at a distance of four hundred feet from the shore or bulk head line. A front of two hundred and thirty-five feet on the pier line is taken up by the foundation itself and the enclosure of sheet-piling.

The position of the tower was such as to occupy the two ferry slips of the Williamsburg Ferry Company, between piers twenty-nine and thirty. These slips had to be vacated before any work could be done on the foundation itself.

Already in July, 1870, negotiations were begun on the site, for the removal of the ferry to an adjoining slip, and also for the removal of a neighboring dumping ground, which would be occupied by the ferry. Possession was obtained in April, 1871, and the construction of the new ferry slips commenced on the part of the Ferry Company and completed in August.

While this work was going on, a length of one hundred feet of the end of pier twenty-nine was removed, and the operation of dredging a level for the reception of the caisson carried on.

The river bed has a slope of ten feet in the width of the foundation and consists principally of black dock-mud overlaying the sand, and covered with sunken timber-cribs filled with stone—the total quantity amounting to five thousand yards. No difficulty was experienced in dredging the bed to a uniform level of thirty-seven feet below high water.

As soon as the ferries were vacated, a pile bridge was built connecting the foundation with the shore, and covering

a space of over four hundred feet in length and one hundred and eighty in width. It serves as a platform for the storage of material and machinery required for the sinking of the caisson, and is in itself a work of some magnitude, requiring in its construction over two thousand piles averaging fifty feet in length.

Borings.

A few borings were made in 1870 from the end of pier twenty-nine, on the site of the foundation, but extending over only one-third of the area. They struck Gneiss rock at a depth of eighty to eighty-two feet below high water, a much more gratifying result than that derived from the first bore-hole, which was made at a point four hundred feet from the foundation, and struck bed rock at a depth of one hundred and seven feet six inches.

Since then holes extended over so limited a portion of the area, it was very desirable to continue them over the remaining portion of the foundation as soon as the adjacent ferry-slips were vacated.

This occurred at so late a day that only four more bore holes could be put down, before the caisson was ready for sinking.

The knowledge derived from nine small bore-holes was therefore the sole information we possessed of an entire area of 17,500 square feet. These holes being moreover confined to the outer edges, left the central portions a *terra incognita*.

The results showed an extreme difference in the levels of the bed rock of twelve feet, the hole of the least depth touching rock at eighty feet below high water, and the deepest at ninety-two feet.

The strata consisted in the main of a black mud deposit of twelve feet, followed by a layer of coarse sand of six feet which overlaid a gravel bed of the same thickness. Beneath the gravel appeared a very heavy deposit of quicksand, varying from fifteen to twenty feet, according to locality, and abounding with boulders in its lower portion, varying from two to five feet in diameter.

This quicksand extended usually to within a few feet of

the rock, and in some instances to the rock itself. But the immediate rock surface was covered with a compact layer of material through which it was impossible to drive a six-inch pipe without shattering it. To drive the pipe one inch only, required thirty blows of a five hundred-pound hammer, falling from a height of twenty feet. But even in such material the quicksand would run into the pipe from below and fill it up for several feet.

When the sinking of the caisson commenced, this question still remained undecided, whether to go to rock or remain above it.

In case of the former alternative, we had the means at hand for blasting the entire rock to a level surface if necessary, and of removing the blasted material, at an additional expense, it is true, of several hundred thousand dollars and six months' more time.

Or, in case the material on the rock proved water-tight, it would be feasible to sink a requisite number of smaller foundations to the bed rock, sufficient to hold the immediate weight above, and then, by a series of smaller coffer-dams or cylinders, remove the remainder of the material and thus get a uniform mass of material between the rock and the roof of the air-chamber.

The only course, therefore, left open under the circumstances was to proceed with the work, and when the caisson had arrived within a short distance of the rock, make a sufficient number of soundings, and then determine upon a course of action when we were face to face with the material.

The character of these bore-holes had also made it apparent that any single plan of operations would not be adequate for removing all the material we would encounter. The immediate river bed consisted of logs and loose dock stones, followed by a sticky, black clay.

These materials could evidently be best removed by dredges working in water shafts.

The river sand and firm gravel beneath would be easier removed through pipes, either by pumps or the air pressure direct.

The coarser gravel, however, would go to the water shafts; whereas the fine quicksand would again be blown out through pipes, until the preponderance of boulders and small rounded stones, compelled a recourse to the water shafts again, provided any dredge whatever had the capacity to remove stones imbedded in quicksand.

For a direct removal of material through locks, no special means were deemed necessary beyond the ample facilities afforded by four capacious air locks already at hand.

New York Caisson.

The plans for this caisson were perfected in the summer of 1870. A contract for its construction was made in October with Messrs. Webb & Bell, the builders of the first caisson, the iron work being done by John Roach & Son, of the Morgan Iron Works. It was built at the foot of Sixth street, New York, the old yard in Greenpoint having been abandoned for ship building purposes.

A rather severe winter with delays on the part of the iron work prolonged the completion of it to the 8th of May, on which day it was launched with the same success attending the first launch. It was then towed to the Atlantic Basin, where seven additional courses of timber and concrete were put on preparatory to its removal to its permanent site. In its

Construction

this caisson is in its general features a duplicate of the Brooklyn caisson. It is built of yellow pine timber, the air chamber being lined with a thin skin of boiler plate on the inside. The roof consists of five courses of yellow pine sticks, twelve inches square; the inclined sides surrounding the air chamber are also of yellow pine, and are nine and a half feet high on top, and taper to a rounded cutting edge of cast iron eight inches wide and enveloped by an armor of boiler plate.

The timbers in all the courses are scarfed and bolted together with screw bolts and drift bolts. About one hun-

dred and eighty tons of bolts were used in the fastenings. The dimensions of the base are one hundred and seventy-two feet by one hundred and two feet, covering an area of seventeen thousand five hundred and forty-four square feet. Its length is four feet greater than the Brooklyn caisson.

The Air Chamber

has a height of nine feet six inches, and is divided into six rooms by means of five main frames. The rooms vary from twenty-five to thirty feet in width by one hundred and two feet long, and are subdivided by lighter secondary frames running through the middle. In addition there are two heavy cross frames extending through the whole length of the caisson. The amount of bearing surface is eighteen per cent. of the whole base, and will be increased to twenty-five per cent. of the whole base, by reason of the sloping sides, in case the caisson should sink into the soil two feet.

The main frames are of solid timber and four feet wide, composed of two central tires of horizontal timber and two outer rows of posts. They are secured to the roof by long through bolts, extending through the lower three courses of the roof, and are heavily braced sideways. The ends of the frames are secured to the sides of the air chamber by knees and iron straps. Each frame is pierced by doorways of ample size to afford communication between the adjoining chambers.

The secondary frames are open work, composed of posts and sills, and can be strengthened if the necessity should arise. An

Iron Skin

lines the inside of the air chamber. The iron is light boiler plates of No. 6 gauge. A light iron was purposely selected in order to overcome to some extent, by its buckling, the difficulty arising from the expansion and contraction of so large a surface rigidly bolted to an unyielding mass of timber. In addition, a series of expansion joints of angle iron were put in transversely to aid in taking up the contraction. No trouble has been experienced from this source since the

launch. All spaces between the skin and the timber have been filled with cement.

The skin performs two principal offices—that of making the air chamber tight; and, secondly, to protect the timber above against fire. It also adds to the strength of the whole structure.

Inasmuch as the skin is pierced with six thousand bolts, besides its own rivets and caulking seams, it was expected that the leakage at first would be considerably greater than in a caisson made tight by caulking with oakum. The expectation was more than realized, since four air pumps were required to inflate the caisson sufficiently to enter it, whereas one pump sufficed for the Brooklyn caisson. As soon, however, as access was had to the air chamber, the leaks were easily stopped, being both audible as well as readily accessible, and it is even tighter than the Brooklyn caisson.

Air Locks.

Two sets of double air-locks are provided, each six and one-half feet in diameter by eight feet in height, and capable of containing thirty men; thus enabling the whole working force of one hundred and twenty men to enter at one locking. The locks are built into the roof of the caisson—the lower half projecting four feet into the air-chamber, and the upper half communicating with a rectangular trough seven feet long, which connects each pair of locks. This trough enlarges above into a circular well of boiler plate eight feet six inches in diameter, which is carried up inside the masonry as the caisson sinks. This style of lock presents some advantages as well as disadvantages, when compared with the old mode. Less time is occupied in passing through a large number of men, and the fatiguing labor of climbing a high vertical iron ladder within the compressed air is avoided.

On the other hand, the locks are dark; they are liable to be flooded by leakage from the well above, thus cutting off both ingress and egress, and in case of an incursion of the waters from below, the avenue of escape is sooner cut off. Steam coils are provided for maintaining a uniform temperature when coming out of the lock.

The idea of placing the air-lock at the bottom of the air-shaft, below the water lenəʌ ị ‘ɹplace of above it, in masonry caissons, is not new, having been proposed in England as long ago as 1831 by Lord Cochran, and again by Wm. Bush in 1841, and still later in 1850 by G. Pfannmuller, of Mayence. It, nevertheless, remained for Captain Eads, in his St. Louis caissons, to make the first practical application of the same on a really large scale in this country.

Excavation of Material.

The removal of the material from the caisson is effected as before, by means of open water shafts and the Cummings' dredges. The shafts, however, in place of being square, are round, having a diameter of seven feet nine inches. The round form is much better adapted to resist a bursting pressure in case it is necessary to blow the water out of them. Since the water shafts have to be cut off when the caisson arrives on the rock, they are provided with caps and air-locks of their own; the old Brooklyn locks being used for the purpose. This will give the opportunity of filling the shafts under pressure.

In addition, fifty-eight iron pipes, of three and a half and four inches diameter, have been distributed throughout the caisson for the purpose of sending out aay sand that may be fine enough to admit of it.

The fact, however, of three bore-holes out of four encountering boulders, made it necessary to provide the means used before for their removal.

The Supply Shafts

are four in number, two of twenty-one inch diameter, and two of two feet diameter, disposed symmetrically throughout the caisson, and arranged in the same manner as those used before. They will prove more than sufficient to supply all the concrete that one hundred and twenty men can dispose of in filling the air chamber.

The Lighting

is done by gas principally, although a double set of pipes has been put in for sixteen calcium lights. Sixty double gas bur-

ners have been provided, giving ten lights for each chamber. The roof and sides have also been painted white, thus increasing the reflecting surfaces.

The management of the gas, however, has been reversed from the Brooklyn arrangement. In one of the chambers below are two gas cylinders, one for oxygen, the other for hydrogen gas, each six feet long, and three feet six inches in diameter. The gas pipes in the chamber connect with these tanks. Compressed gas is forced into them through special pipes leading down from above, and the requisite excess of pressure over the caisson pressure, is maintained by a head of water forcing the gas out of the tanks into the pipes. On the dock above, at an elevation of a few feet above the water level, are the two other cylinders, the exact counterpart of those below. They are partly filled with water, which communicates by pipes with the lower tanks, and forces the gas out of the latter. The stage of water in the upper tanks will always indicate the amount of gas in the lower tanks, and as the caisson sinks it, of course, increases the head of water, for forcing out the gas in the exact ratio required. The cost of gas is only one-third that of candles, besides giving a much better light and making no smoke.

Sea Worms.

Particular care has been taken in this caisson to protect the timber from the sea worm on the outside. This protection is only required while the caisson is afloat and while it is being sunk—ultimately all the timber will be submerged far below the river bed where the worm never penetrates. The borings, moreover, showed that the layer of gravel occurring twelve feet below the river is permeated with fresh water which is fatal to the teredo.

Every beam on the whole outside of the caisson and also on top of the sixth roof course is thoroughly caulked, both with a view to keep out the salt water, as well as to aid the air-tightness, and to relieve the iron skin from any back pressure.

In the next place the same surface is heavily graved with

a composition of coal tar, rosin and dydraulic cement, the latter material having sufficient body and grit to dull the boring apparatus of the teredo. Coal tar alone has but little efficacy, because the animal does not digest the material through which it bores.

Over this coating there extends an unbroken sheet of heavy tin, covering the outside and the top of the sixth course. Every seam is soldered air-tight, and a layer of tar paper put above and below the tin. On the outside of this is the four inch yellow pine sheathing of the caisson which has been creosoted with ten pounds of oil to the cubic foot.

These precautions will not seem superfluous when it is remembered that the young sea-worm is a microscopic animal, less than the sixteenth of an inch in diameter, and can penetrate any crevice that water can pass through.

The course above this is also caulked and is protected on the outside like the lower courses.

We are thus provided with an additional air-tight layer in the caisson, which will come into play in case of accident to the iron skin.

The seven courses of timber immediately following the caisson proper are all laid with cement spaces between the timber; they are surrounded by tarred sills, and the tin and creosoted sheathing is carried up outside the whole extent. The courses above that are completely enveloped in concrete.

Floor.

The caisson was launched with a temporary floor, extending over the entire base. This was made necessary by reason of the shallow water in front of the launching ways. This floor remained in until the caisson was permanently grounded on the river bed, and helps materially in maintaining a level position of the same.

The air-chamber was not inflated before the caisson had touched bottom, and enough masonry laid to prevent its rising at high-tide from the effect of the air pressure. This floor then came into play to distribute uneven pressures until access was had to the air-chamber and the work of excavating was commenced.

Table of Quantities.—New York Caisson.

Length over all	172 feet.
Breadth	102 "
Height	14 " 6 inches.
Area of base	17,554 square feet.
Quantity of timber	118,000 cubic feet.
Weight of bolts	180 tons.
Weight of iron work	200 "
Launching weight of caisson	3,250 "

Preparations for Sinking the Caisson.

Owing to the vexatious delays in obtaining possession of the ferry slips adjoining pier twenty-nine, nothing of any importance could be done in the matter of locating machinery or workshops until August, when the ferry-boats finally ceased running into their old slips, and the new boundary line was established between the property of the Ferry Company and the Bridge Company.

The month of August and part of September were employed in building a pile dock from the bulkhead line out to the caisson, averaging four hundred and fifty feet in length and one hundred and eighty feet in width, inclusive of the old pier.

At its outer end was formed a square inclosure, open on the river side, for the purpose of receiving the caisson when it was ready to be towed up from the Atlantic Basin.

The amount of space on the pier line was so scant, that a narrow platform of ten feet width constituted all the available room between the sides of the caisson and the fender rack of the ferry on the one side, and the crowded shipping of the adjoining slip on the other, showing that economy of space during erection is not the least of the merits of caisson foundations.

Inclosure of Caisson.

For the purpose of obtaining still water, the caisson was surrounded by a wall of sheet piling, composed of white pine plank fifty feet long and six inches thick. This served to break the force of the tidal current, which often runs at the rate of four miles per hour, and would produce a pressure of ninety tons against the structure at a time when it is most

important to have it stationary in its true position—just before touching bottom.

This entire work of pile-driving and dock-building was superintended in the most efficient manner by Mr. George McNulty.

Within the enclosure thus formed the bottom was dredged to a uniform level of thirty-seven feet below high water, by means of the clam-shell dredge of Messrs. Morris & Cummings, who did this portion of the work under contract.

They removed in all seven thousand yards of material, of which one thousand five hundred yards consisted of dock stone and logs.

Machinery and Workshops.

On the pile platform thus prepared were erected two engine houses for the dredge machinery, which was transferred from the Brooklyn side, and had been enlarged to correspond to the increased depth to which this caisson would go.

Two double hoisting engines were set up, both for unloading stone and setting stone on the caisson.

Four additional double engines were provided for unloading sand, gravel, coal, cement, and lumber, for hauling dredge cars back and forth, pumping gas and mixing concrete.

The principal building, however, was the

Compressor House,

for supplying air to the caisson.

The air-pumping machinery comprised thirteen of the Burleigh rock drill air compressors, ranged in a single row, each discharging its air into one common ten-inch main overhead, and provided with suitable valves to shut it off from the main system.

Every compressor has its own steam boiler of the vertical tubular type, so connected as either to work independently or as an entire set. Pumps for cooling the air were also in duplicate.

Six of these compressors were brought from the Brooklyn caisson, the remaining seven being purchased anew.

From the compressor house the air was carried by a ten-inch cast-iron pipe through an intermediate air reservoir, for a distance of one hundred and fifty feet under the dock, to the caisson, whence two branches of six-inch rubber hose continued it by means of the supply shafts to the air chamber below.

The idea governing the general arrangement of the air pumps was the necessity of an uninterrupted supply of air, day and night, for at least a year, under a constantly increasing duty.

This could only be done by a number of smaller machines, so that if one were out of repair the remainder would have sufficient capacity for the work.

Besides the buildings for machinery and offices, a number of sheds were erected for the accommodation of blacksmiths, carpenters, machinists, for cement and for general stores; also wash-room, clothes-houses, hospital, and resting-rooms for the caisson men.

Three unloading derricks, a double railroad track, and two overhanging platforms comprised the preparations on the dock for supplying the caisson derricks with stone.

Towing the Caisson into Position.

All preparations for receiving the caisson being completed by September 11, it was on that day towed from the Atlantic basin to its final resting-place. While at the basin, seven additional courses of timber and concrete had been built upon it under contract with Mr. D. Burtis, Junior. All the outer seams were caulked and protected by felt, tin, and creosoted sheathing. The various pipes, shafts, and locks were also carried up to the necessary height.

This work was very carefully attended to under direction of Colonel Paine.

Four air pumps and boilers placed on the deck served to inflate the structure during the voyage. Its draft of water when empty was twenty-three feet, reduced by inflation to seventeen.

Total weight, seven thousand tons.

Under the skillful guidance of Captain Murphy, and the assistance of six tugs, the trip was safely performed in two hours and a half. A few days' work then sufficed to complete the pile inclosure and confine the New York caisson in its permanent position.

Additional Timber Courses.

By the 1st of November the last of the timber courses was laid under the Burtis' contract.

The great timber foundation was now complete! It contains twenty-two feet of solid timber above the roof of the air chamber, seven stories more than the Brooklyn caisson, and since the strength of such structures varies as the square of the depth, we may consider it to be nearly twice as strong as its Brooklyn brother.

The result has proved this. At a depth of seventy-eight feet, and a load on its back of fifty-three thousand tons, not the slightest sign of weakness or crippling has been discovered! No deflection has been observed in the roof, even when the main frames and edges below were entirely dug out and not resting on the ground. The principal object of these frames is, at most, a precautionary one, besides serving to fill up the air-chamber to the extent of their bulk.

Outer Coffer-Dam.

An outer coffer-dam has been carried up outside of the masonry. It is composed of upright posts 12x12 placed four feet apart, with an outer planking of white pine six inches thick. Shores extend from each post to the masonry, arranged in tiers for every three courses of stone.

The coffer-dam commences seven feet below the upper course of timber, where it is attached to the caisson by a heavy creosoted sill and screw-bolts. The space between it and the timber is filled with concrete, fourteen feet in height, beneath which the outer covering of tin extends for five feet. The upper layer of timber is covered with three and one-half feet of concrete, amounting in all to three thousand five hundred yards.

Under certain circumstances it would have been possible to omit this coffer-dam and save the considerable expense attending it. On the Brooklyn foundation no outer coffer-dam was used, the depth of water being too shallow.

In any case it was necessary to carry up the dam for a height of twenty-five feet. When the last course of timber was laid, the caisson was still floating two feet from the bottom at low water, and ten feet at extreme high water. To keep it on the bottom at extreme high water required four courses of masonry, and when inflated with air, three additional courses were required.

Owing to the rise and fall of the tide and the great top-weight of the structure, the requisite buoyancy and stability could only be attained by the displacement of a coffer-dam, especially as the usual appliances of suspended screws for keeping the structure level when afloat were obviously inapplicable.

It had also been intended to surround the tower by a permanent dock of stone and concrete, the foundations of which could now be laid within this coffer-dam at a moderate expense. This intention was, however, abandoned owing to the necessity of strictly confining the expenditure of money to the bridge proper. At present the coffer-dam has been designedly filled up with sand, and forms part of the timber dock extending to the tower masonry.

It will last for fifteen years without renewal.

The coffer-dam also formed a protection to all the caisson pipes, and made it possible to repair them when out of order. These pipes consist of four supply shafts of two feet diameter, and fifty pipes of four inches and three and a half inches. None of them were built in the masonry, but came up between the wall and the coffer-dam.

On one occasion, through the accident of a large stone falling, a supply shaft was broken off at the timber-line, and would have been lost but for the coffer-dam. But the chief benefit derived from it was the fact that the masonry was laid below the water during the most of the winter. The work of sinking the caisson could, therefore, proceed uninterrupt-

edly, no matter if the masonry stopped on account of the cold weather.

Inner Coffer-Dams.

Two smaller, inner coffer-dams served as a water-tight lining to the main well holes of the masory. Within them were carried up the sections of water shaft, as well as curbing of the air-lock shafts.

As far as the timber extends, this curbing consists of a boiler-plate shell, stiffened by flanges and secured to the timber by wood-screw bolts. The wooden curbing of six-inch plank was notched, dowelled, caulked, and further protected on the outside by a ring of concrete between it and the inner coffer-dam. The leakage has been practically none.

Derricks and Masonry.

The stones were laid by three boom derricks, similar to those employed on the Brooklyn foundation. They were guyed solely from the caisson itself, so that the settling of the latter did not disturb the guys. Every twenty-feet the derricks had to be raised, an operation requiring a few days.

Twenty-five courses of stone have been laid on top of the timber, making a height of fifty feet, and amounting in all to eleven thousand seven hundred cubic yards of masonry.

The stones are all bedded down to a uniform rise in one course, with joints dressed down to moderate projections, the rise varying from twenty to thirty inches. Both granite and limestone were used indiscriminately, the former coming principally from Maine, and the latter from Kingston, Lake Champlain, and Cacajoharie.

Owing to the early commencement of winter, much of the stone in transit for the New York tower, was frozen in, and, in order to keep on setting, it became necessary to use all the backing intended for the Brooklyn tower. This has been supplied since, and at no time has there been any stoppage for want of stone.

During the severest weather, work was suspended for several days at a time, the coffer-dam preventing the river from covering the wall.

Work in the Air Chamber.

By the end of November sufficient weight had been placed on the caisson to prevent its rising for a short time at low tide when inflated.

A gang of laborers worked for several hours every day, taking up the floor of the air chamber and removing the principal obstructions in the shape of dock logs and stones under the edges and frames.

In proportion to the weight above, the length of time spent below was increased, until two regular gangs were at work, four hours on and four hours off, the caisson being now permanently grounded.

Each gang consisted of about seventy laborers and seven foremen. In a short time an extra night gang was also established. Two weeks were consumed in removing and taking out the floor.

This floor proved a valuable adjunct in giving the caisson a level bed on which to rest, and in preventing it from tipping up on either end before sufficient weight had been placed on it.

The character of the work at this particular time was more disagreeable than at any subsequent period. This location had for many years been the site of the principal dumping-ground for city garbage. The mud abounded in decaying animal and vegetable remains. Although the odor of these was checked while imbedded in the salt water mud, it came forth in its original strength when brought in contact with the caisson air. More men were overcome by foul air than by compressed air.

By keeping the material constantly covered with water, so as to cover the odor, it was gradually disposed of through the water shafts.

This black dock mud is really a clay, and is the silt brought down by the North River, merely lacking time and pressure to make it as hard and tenacious as ordinary clays. It derives its black color from sewer discharges, but is by no means their product.

The coarse river sand and beach gravel beneath the mud

soon created a change for the better below. The water was easily expelled by the air, leaving it dry under foot.

By this time also the gas-lights were in complete operation in all the chambers, giving ample light in every part. Two coats of whitewash over the roof and walls aided in reflecting it and making the air chamber an agreeable spot compared with what it was at the beginning.

The performance of the

Dredges

in the mud and coarse sand and gravel was very satisfactory. They constantly maintained a hole about six feet in depth under the water shafts, and removed from three hundred to four hundred yards per day.

Water for the shafts was supplied by two sets of four-inch pipes, one of fresh water from the city mains, the other connecting with a force pump on the dock, which threw in a constant supply of salt water under great pressure, and proved of considerable use subsequently in loosening boulders under the water shafts. Owing to the fact that the shafts were fifty feet from the nearest edge of the caisson, a supply of water from the river without could at no time be relied upon.

Throwing Out Sand Through Pipes.

About fifty pipes were located in the roof of the caisson, passing up through the timber, and discharging above beyond the coffer-dam. In size they varied from three and a half to four inches.

The precise mode in which they were to be utilized in throwing out sand had been, to a certain degree, left undetermined. Two modes were applicable, either to throw out the sand by direct force of air, or else have recourse to sand pumps.

Very satisfactory experiments had been made the year before in the Brooklyn caisson in throwing out sand through pipes by air pressure.

The same mode had been used ten years previously by General S. Smith and Mr. C. C. Martin in blowing sand out

of cylinders, and more recently at Omaha under similar conditions.

The apparatus is very simple, consisting merely of a piece of pipe and a through way cock extending into the air chamber.

Moreover, the objection of a very small air space to draw upon, as is the case in pneumatic cylinders, would not apply in a large caisson, which constitutes a large reservoir in itself, and would retard any rapid fall of pressure.

Another strong reason in favor of the air process was this: An air-chamber with an iron skin can be made practically air-tight, but a certain quantity of air must be thrown in per minute to keep the air fresh and fit to live in. This air would usually escape under the edges and do no work. Now, why not allow it to escape through pipes and at the same time carry out sand with it, and not be wasted? There was ample air-pump power, thirteen compressors having been provided, of which number four only were required to supply the leakage, but six to supply sufficient fresh air.

Any other mode, however, of sending out the material would require extensive provision of machinery in the shape of pumps, boilers, and pipes, entailing an additional cost of at least $40,000, and difficult of application for want of the required space around the foundation.

In view of these considerations, it was first determined to give the air system a thorough trial.

The result has been eminently satisfactory. At a depth of sixty feet sand was discharged through a three and one-half inch pipe continuously for half an hour at the rate of one yard in two minutes. This represents the labor of fourteen men standing in a circle around the pipe and shoveling as fast as their strength would permit. At this depth the supply of air was sufficient to supply three pipes at a time. This may appear a small number compared with the whole number of pipes, but yet was enough to keep at least sixty men busy.

The labor in itself is very fatiguing, making frequent resting spells necessary ; more hands are required to throw the sand to the pipes than to feed them, and a large proportion of labor is expended in digging out under the frames and edges.

The most economical mode of working these pipes was made the subject of many trials by Col. Paine and Mr. Collingwood, the engineers in charge in the caisson. Trials were first made with flexible pieces of hose provided with strainers at the end. These became choked too easily both in the holes of the strainer and in the hose. The strainer was then removed and a shorter piece of vertical hose used, in connection with a piece of iron pipe. This, in turn, was discarded for a stationary iron pipe, extending within a foot of the ground and provided with a stop-cock below the roof.

Around the lower end of this pipe the sand and earth were heaped up in shape of a cone, while another workman attended to the opening or shutting of the air cock.

As the pressure increased, the lower orifices of the pipes were reduced to three inches and finally two inches, the same quantity being discharged with a smaller loss of air.

The material, of course, passes out with tremendous velocity, stones and gravel being often projected at least four hundred feet high. When the feeding below was too slow or irregular, the sand would be thrown very high, but, by practice, the discharge became more uniform.

In order to deflect the sand at the top of the pipe at right angles, both wrought and cast iron elbows were used at first. The sand blast would generally cut through these in an hour or two, sometimes in a few minutes, the thickness of iron being one and a half inches. That portion of the elbow struck by the sand was then made open and provided with a thick cap of chilled Franklinite iron, capable of being reversed when worn on one spot. These would at most last two days. Finally all elbows were taken off, heavy granite blocks placed over the mouth of the pipes,

and the material discharged against them into the coffer-dam.

Several minor casualties occurred from the discharge of stones, such as a boatman on the river having his finger shot off and a laborer being shot through the arm by a large fragment.

Some inconvenience was experienced from the wearing out of the ends of the pipes below in the air chamber. The cocks also wore out rapidly, owing to careless attendance in not opening them all the way. The pipes in the timber did not wear. When a four-inch pipe had become cut, a three and a half-inch pipe was driven inside of it, then a three-inch, and at last a two-inch. But they lasted so well on an average, that one-third of the pipes were never used.

QUICKSAND.

When the quicksand was fairly entered upon, it was found that the dredge buckets no longer operated to any advantage. This sand, in combination with small stones and boulders, will compact to a mass as hard as rock, which cannot be penetrated by the teeth of a bucket, and even the point of a crowbar can scarcely be driven into it.

Some slight relief was experienced by the use of a hose under the shaft to stir up the material, but even then the sand was so fine as to escape through the crevice in the buckets.

The sand pipes became henceforth the sole reliance, and answered admirably, until the coarse gravel and stones became so plentiful as to choke the ends of the pipes, making it necessary to stop for a moment to remove the stone.

The work of the last ten feet, from sixty-eight to seventy-eight, was, on this account, very tedious and slow. Previous to this the progress had, at times, averaged a foot per day of sixteen hours, implying the removal of six hundred and fifty yards per day, but toward the end this rate decreased to one or two feet per week.

Cutting off the Water Shafts.

At a depth of sixty-eight feet a number of boulders were encountered under one water-shaft, too large to be moved either by the dredge or by outside appliances. It therefore became necessary to cap the shaft and blow out the water, similar to the operation so frequently performed in Brooklyn. On top of the cast-iron cap was placed one of the old air-locks, so as to afford access into the shaft thereafter.

After the water was blown out and boulders removed, the shaft was cut off near the roof of the air-chamber. The same process was repeated with the other shaft. During this time the caisson was kept from sinking by banking up the frames and edges with earth.

The air pressure against the caps of the shafts was one hundred and thirty-three tons. The individual sections had been tested to twice this pressure before, but by way of precaution an additional dead weight of fifty tons was placed on them.

Where water shafts are used, it is absolutely necessary to make provisions for capping them.

Soundings for Rocks.

At a depth of seventy feet, soundings were begun in the air-chamber for the location of bed rock, by means of a pointed rod, ten feet long, driven in by sledges.

A trial was made to sound by means of a pipe and water jet, but was abandoned on account of the numerous stones. These probings were carried on daily for a month, until a clear idea of the form and depth of bed-rock was attained.

The surface was evidently very irregular, composed of alternate projections and depressions, the extreme difference in elevations encountered being sixteen feet, and occurring chiefly along the water edge. Throughout the central portion, however, and covering at least two-thirds of the entire area, the irregularities were much less, amounting to only three or four feet in a length of one hundred and sixty, and width of about seventy-five feet.

The caisson would apparently settle on a broken ridge of rock, running diagonally from one corner to the other, and having a moderate dip of perhaps five feet in the hundred toward the land; but falling off very suddenly toward the east corner in number one chamber.

With these facts before us, it was evident that it would be a matter of immense expense and great loss of time to blast down the rock to a comparatively level surface; but unless this was done, it would appear equally dangerous to all the caisson to rest on the rock at one end and not on the other.

Fortunately one circumstance put a more favorable appearance upon the case, and that was that the top of the rock was found to be covered for a depth of two to four feet by a layer of very compact material, so hard that it was next to impossible to drive in an iron rod without battering it to pieces.

Moreover, where the rock lay the lowest, this layer of hard material had its greatest thickness.

It was good enough to found upon, or at any rate nearly as good as any concrete that could be put in place of it. In extent it covered fully three-fourths of the caisson, leaving a narrow strip of quicksand along the land edge, and a triangular portion over part of number one and six chamber.

Since the lower line of quicksand sloped at the rate of six feet in the hundred, it became necessary to penetrate about five feet into the hard ground on the water edge before the bottom of the quicksand was reached on the land side. The number of boulders found in it was very large, much greater than were found in the same space on the Brooklyn side.

It was determined to rest the caisson on this material at a depth of seventy-eight feet. The projecting peaks of bed rock which already made their appearance at seventy-five feet, were blasted down for some distance under the shoe, and covered with a foot of compressible earth.

In number six chamber a trench was sunk through the remaining quicksand under the edge, and filled with con-

crete to confine the portion remaining within; a task of no small difficulty, owing to the influx of water and sand.

Any other small irregularities will be fully equalized by the great timber platform above.

Bed-rock.

The first spurs of bed-rock were encountered at a depth of seventy-five feet, under the shoe on the water-side. It would seem that the caisson had been scraping along a vertical wall of rock for the previous five feet at that spot.

The rock is the ordinary Gneiss found on Manhattan Island with a dip almost vertical. No part of its surface shows the rounding action of water or ice. On the contrary, the outcrop is in the form of sharp thin ridges, with steep vertical sides occurring in parallel ranges.

On such a bottom no sliding can ever take place, no matter what the average slope might be. At 78 feet the outcrop was struck in a number of places and blasted down a short distance below the edge. A slight covering of soil gave the necessary amount of compressible material above these rocky points. Nearly all of them occurred under the edge on the water-side, a favorable circumstance, since the resultant of pressure is in that direction.

No fresh water was found on the rock, but salt water entered upon a reduction of air pressure.

Effects of the Compressed Air on the Men.

These were not so serious as first anticipated. The few cases of death that occurred could in but two instances be charged to the direct effects of pressure.

As the latter increased, the working hours below were gradually reduced from four hours to two hours, twice a day, at thirty-five pounds. It is true that scarcely any man escaped without being somewhat affected by intense pain in his limbs or bones or by a temporary paralysis of arms and

legs, but they all got over it, either by suffering for a few days outside, or by applying the heroic mode of returning into the caisson at once, as soon as the pains manifested themselves, and then coming out very slowly.*

The shortening of the hours of labor produced the best results in keeping the men in good condition, but even this was not necessary for all constitutions, because some could remain below with impunity for six hours at the highest pressure.

After the locks were passed the men had their choice of coming up either by an elevator or by circular stairs.

During the winter months all tendency to congestion of the lungs, owing to the sudden change of temperature in coming out of the locks, was controlled by means of steam coils in the latter, so arranged as to warm the air when coming out of the lock and to cool it when passing in.

The general condition of the air below was very pure, due to the absence of candles and illumination by gas alone.

Mr. Collingwood found that as the pressure increased the gas-burners gave more light, and at thirty-five pounds a one-foot burner gave as much light as a four-foot burner outside. We therefore had a maximum production of light with a minimum production of irrespirable gases.

The services of Dr. A. H. Smith were engaged for the purpose of attending to all caisson cases and examining new candidates for work below. He has been quite successful in

* Among the numerous explanations offered, as to the causes of these pains the most satisfactory one seems to be that of Prof. Rameaux, of Strasburg, in whose opinion these accidents are due to the fact that the normal gases of the blood (carbonic acid, oxygen and nitrogen), dissolve themselves to a high degree under the influence of extreme pressure, and return into a gaseous state as soon as the pressure is reduced to one atmosphere, obstructing the views and exposing the patient to the same dangers that would be produced by an injection of air into the veins.

A rather severe personal experience of the writer, resulting from a stay of several hours in the New York caisson, would seem to confirm the above view to some extent. Relief from the excruciating pain was afforded in his case by a hypodermic injection of morphine in the arm, where the pain was most intense, and a further stupefaction by morphine, taken for twenty-four hours internally until the pains abated.

his treatment, and it is to be hoped that his experience will be made public for the benefit of future works.

The fact remains, however, that the effects of compressed air on the human system constitute the principal difficulty attending deep pneumatic foundations. Men are somewhat difficult to get, wages are high, and the time of labor becomes so short that the work must necessarily be done under a disadvantage and under an immense amount of supervision, where it is at all difficult or different from ordinary digging in a uniform material.

Besides two general foremen and fifteen under-bosses, it required the daily attendance of both Col. Paine and Mr. Collingwood, assisted occasionally by Mr. Martin and Mr. McNulty, to keep matters moving smoothly below and in conjunction with affairs above.

An ingenious mechanical telegraph, contrived by Col. Paine, proved of great assistance in keeping up communication between the upper and lower world.

Gas.

The ordinary street gas has been the only agent used for illumination. Sixty burners, divided among the six chambers, gave all the light required. The gas was burned under a pressure of one or two pounds in excess of the caisson pressure, and was at all times uniform and plentiful in supply.

A gas pump above forced the gas steadily into the tank below, and as the latter would fill with gas it raised the column of water in the tank above, where, at a certain stage, a float controlled the throttle-valve of the gas pump, and thus regulated the supply of gas within restricted limits,—the whole arrangement being self-acting.

One interesting fact was observed which may possibly be new, and that is, that in compressed air all gas-lights become sensitive flames, answering to the stroke of a hammer on a piece of iron, or even to tones of the voice.

Movements of the Caisson.

The downward movement of the caisson has been under perfect control throughout the whole of the sinking. It usually occurred at low tide and was very gradual, owing principally to the wide frames and broad shoe.

While the caisson was passing through the mud, river sand, and gravel, the frames sank through the material without digging, but in the quicksand and harder material below, the whole frames had to be dug out underneath before settlement would take place.

The caisson also sank perpendicularly in its true place, no movement occurring in any direction. This result was principally owing to the facility with which it was kept level by digging.

The side friction was considerable, but difficult to estimate, because the frames and shoe were seldom entirely clear. It could not have been less than six hundred pounds per square foot of external surface, varying with the amount of air passing out under the shoe.

The total resistance offered by the side friction is, however, quite small when compared with the total bulk. At a depth of seventy-eight feet the side friction amounted to six thousand tons, whereas the weight of the whole foundation, including masonry, was fifty-three thousand tons.

At seventy-eight feet the excess of the downward pressure of the caisson over the upward pressure of the air at low tide would average from ten to twelve thousand tons, not including side friction. The air pressure has, however, frequently run so low as to give an excess of downward pressure of fifteen thousand tons. An excess of overweight is in all cases an advantage, as it saves considerable digging.

The experience with this foundation goes to show that a larger caisson is much easier to handle, is safer and under more perfect control than a smaller one. The labor question, however, becomes the most serious drawback where a considerable number of men have to be brought together under

abnormal circumstances. The forces of nature may be measured and brought under control, provided they are properly understood, but human nature is not so amenable to laws.

Filling of Air-Chamber & Completion of Foundation.

The concrete for filling the chamber is all mixed above and let down through the supply shafts ready for distribution below.

No brick pillars were used as under the Brooklyn caisson, the bearings of the frames being so wide as to be equal to all contingencies when once uniformly packed under with concrete. Enough stones and earth were left below to reduce the amount of concrete required to 3,300 yards, about the same amount as in the Brooklyn caisson. The filling in took place in such a manner as to leave the final exit by means of the water-shafts; all the remaining quicksand was dug out below, down to the hard pan and worked up into the concrete.

In six weeks after commencing the filling in there remained only two hundred and eighty yards, showing an average of nearly one hundred yards per day.

By July 20th the water shafts were finally filled, the air pressure taken off, and the locks on the water shafts removed Several trials were made to take off the air pressure before the filling was complete, but the water invariably came in when the pressure was reduced below thirty pounds. Up to the end as many as five air pumps were needed mainly because the concrete was so easily traversed by the air. Another month was consumed in removing the water shafts, air shafts, inner cofferdam, and outer shores, and in filling the two large well holes with concrete, as well as the other shafts and smaller pipes, and in completing the dock around the tower. The laying of stone was resumed before the air chamber was entirely filled.

The New York foundation was now finished.

CONCLUDING REMARKS.

The pleasant task remains yet of expressing my thanks to the gentlemen who have so ably assisted in the prosecution of the work, and to whose untiring industry, constant watchfulness and sound judgment, is mainly due the success which has attended it to the present time.

The work in both caissons has been carried on under the daily supervision of Col. Paine and Mr. Collingwood, relieved at times by Mr. Martin and Mr. McNulty, whenever the numerous outside duties of these latter gentlemen would permit.

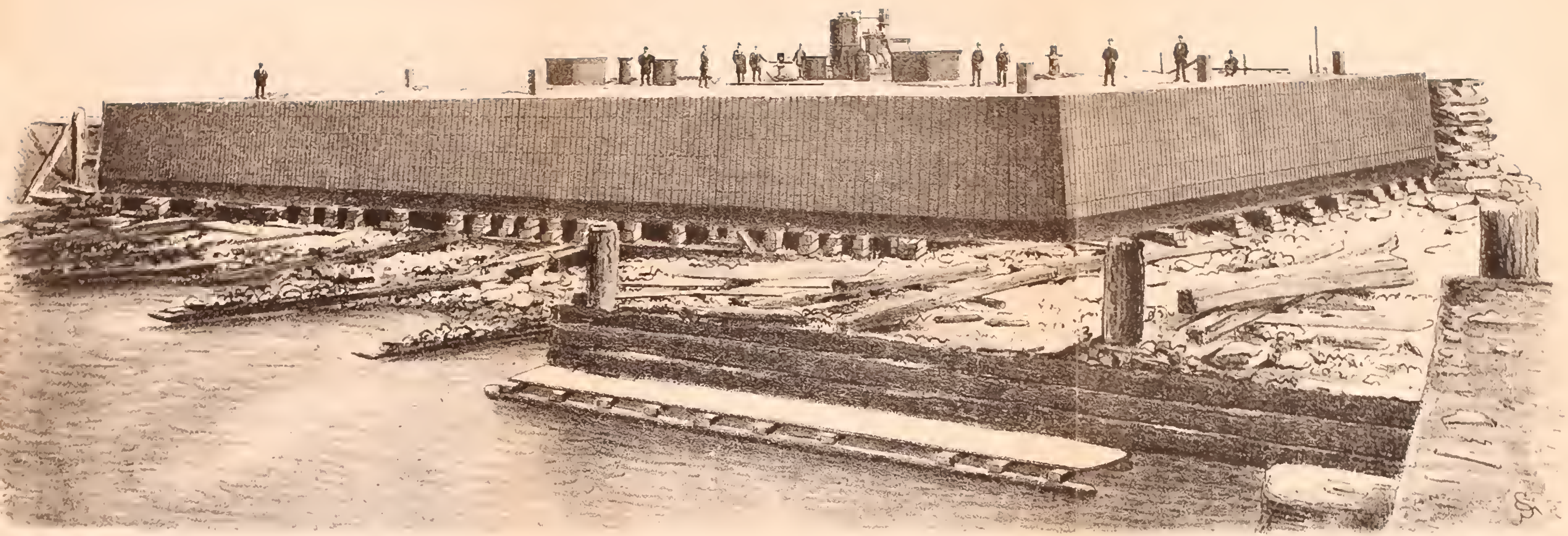
The labor below is always attended with a certain amount of risk to life and health, and those who face it daily are, therefore, deserving of more than ordinary credit.

The general foremen below have been Messrs. Young, Clarke, Creene, Woliver O'Malley, and Korner, assisted by twelve under foremen.

The masonry, carpentry, and machine departments have, throughout, been most efficiently attended to by Messrs. Douglass, Farrington, and Smith; while the draughting-room has been in charge of Mr. Hildenbrandt, and occasionally Mr. Vonder Bosch.

To Mr. Horatio Allen, consulting engineer, my acknowledgments are due for his counsel and advice.

In regard to the relations of the engineering department and the general management, it gives me pleasure to bear testimony that all requisitions from the engineer department have been met with the utmost promptness, both in respect to quantity as well as quality, and that the relations of the different executive branches have been conducted with a mutual co-operation, conducive to the highest results, both in efficiency and economy.



BROOKLYN CAISSON.
EAST RIVER BRIDGE.

Engineer W. A. ROEBLING.

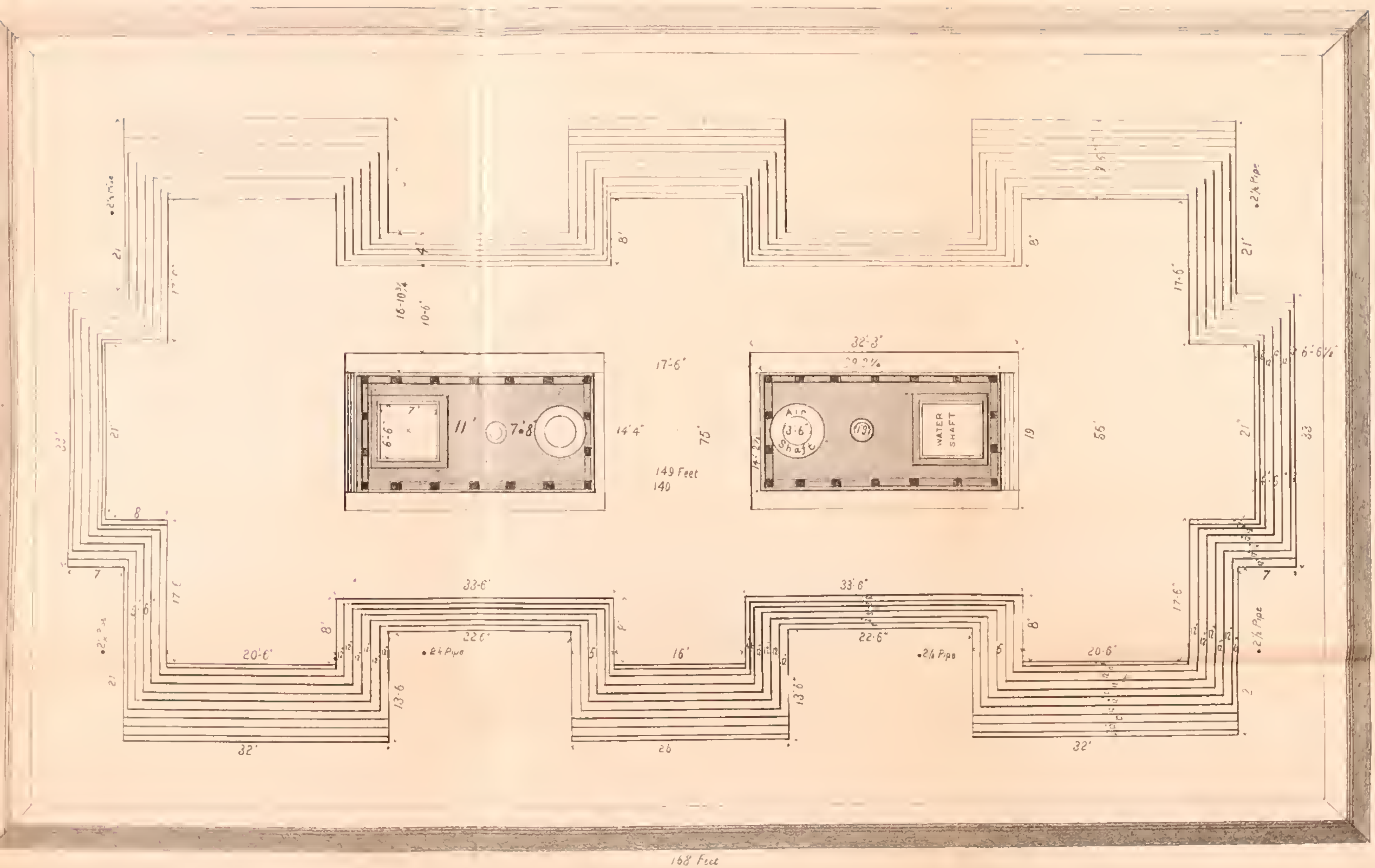
DIMENSIONS.

Length	168	Feet
Breadth	102	,,
Height	14 ½	,,
Height of Air Chamber	9 ½	,,

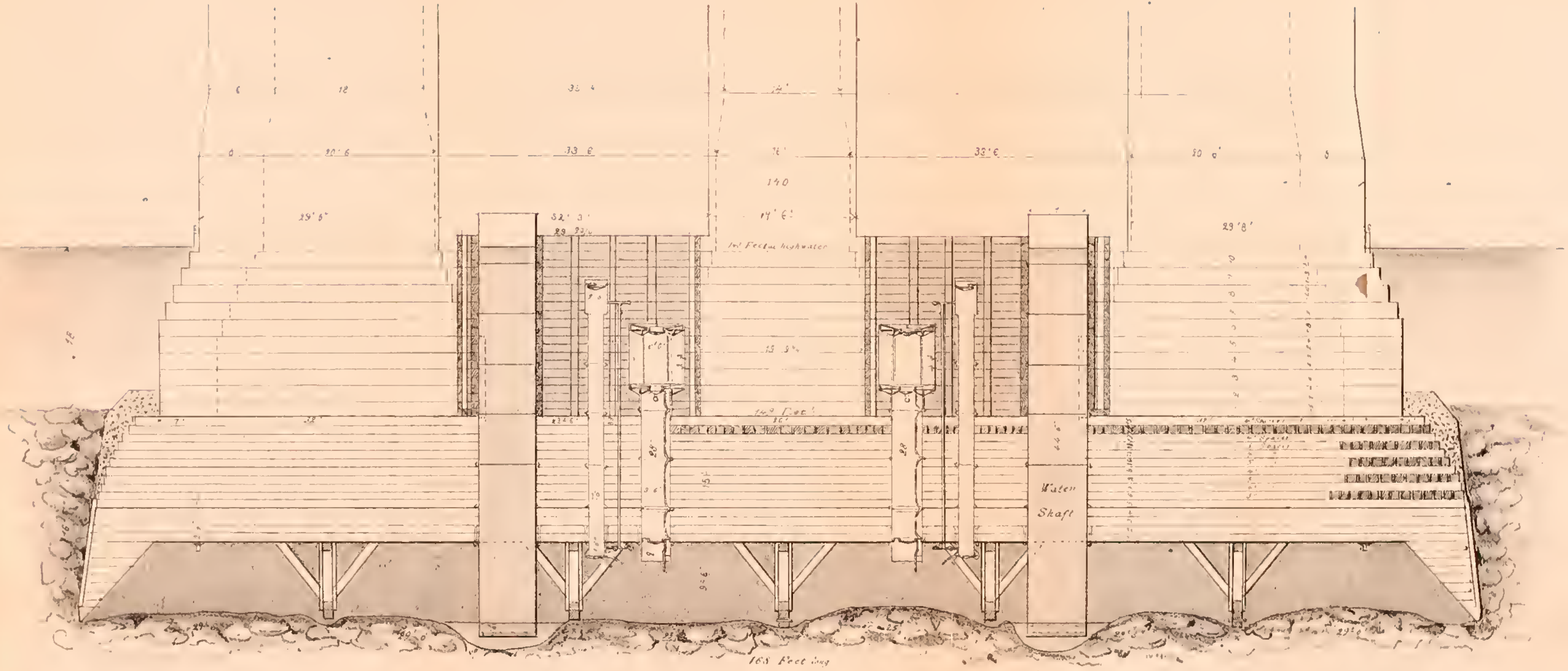
CONTENTS.

Cubic Feet Timber	110.000
Tons Iron	230
Launching Weight (Tons)	3.000
Launched March	1870.

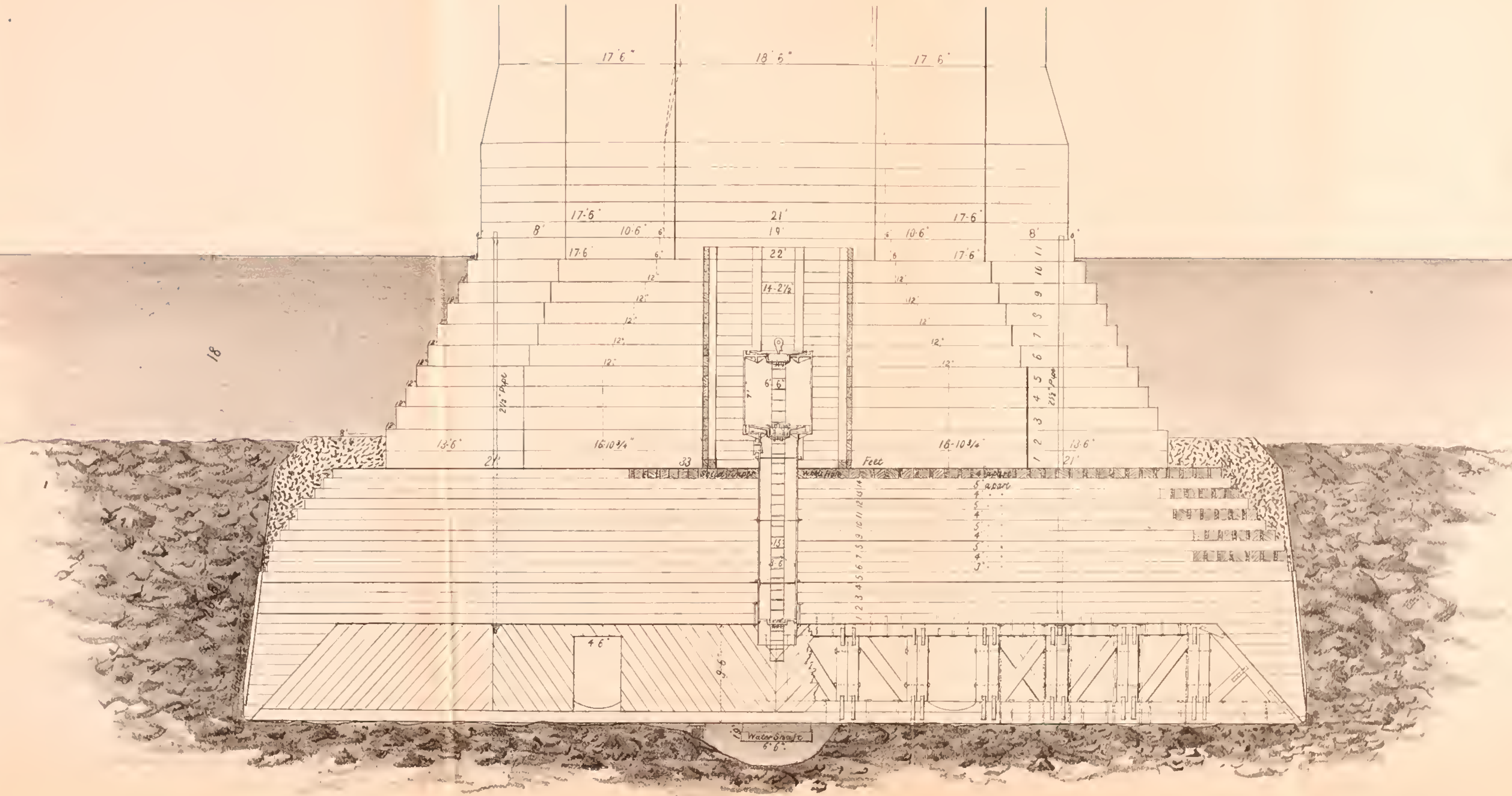
PLAN
of the
BROOKLYN CAISSON
of 12th course



BROOKLYN CAISSON
LONGITUDINAL SECTION
through centre



BROOKLYN CAISSON
TRANSVERSE SECTION
through air-lock.



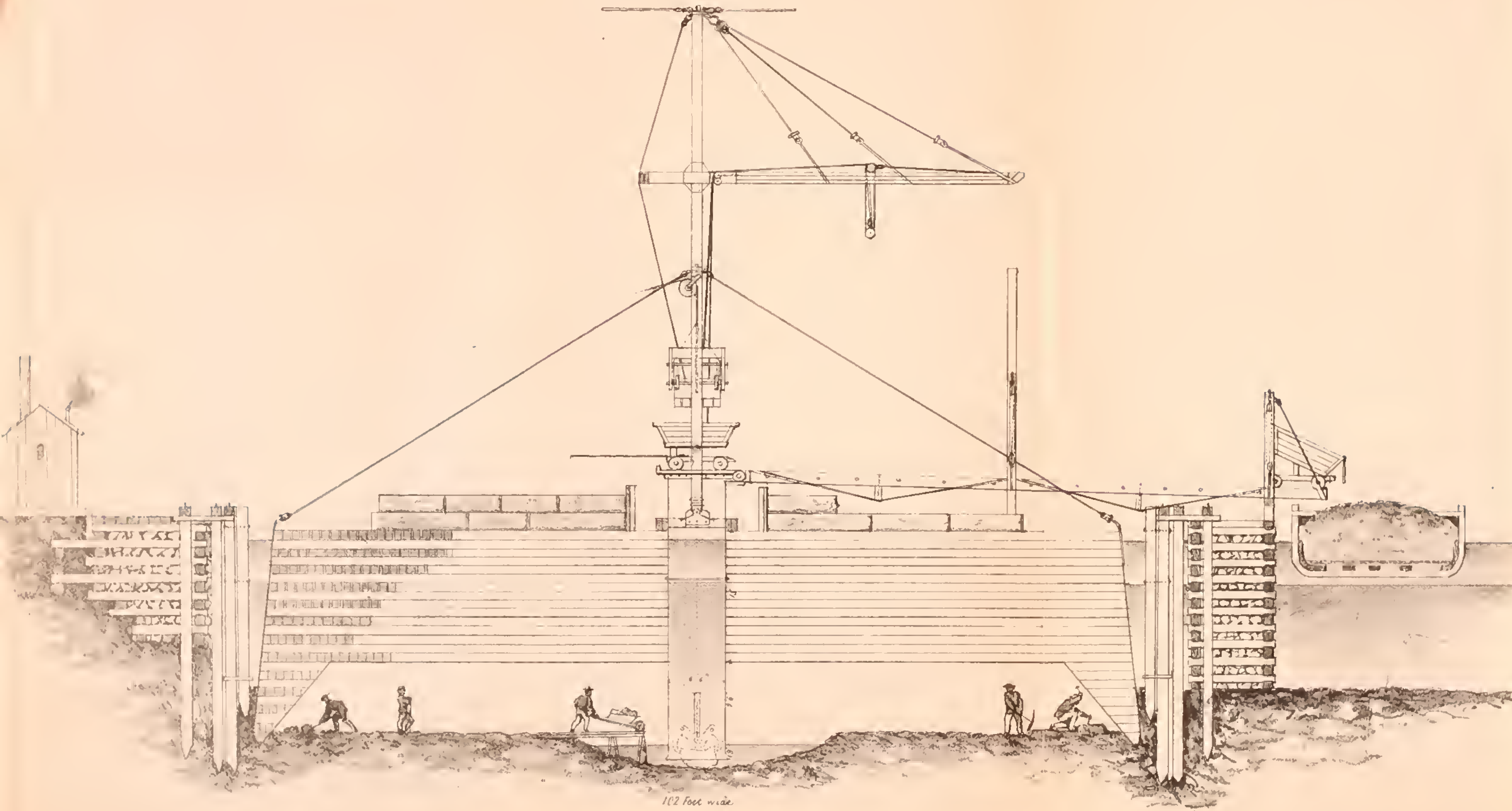
102 Feet wide

Arrangement of

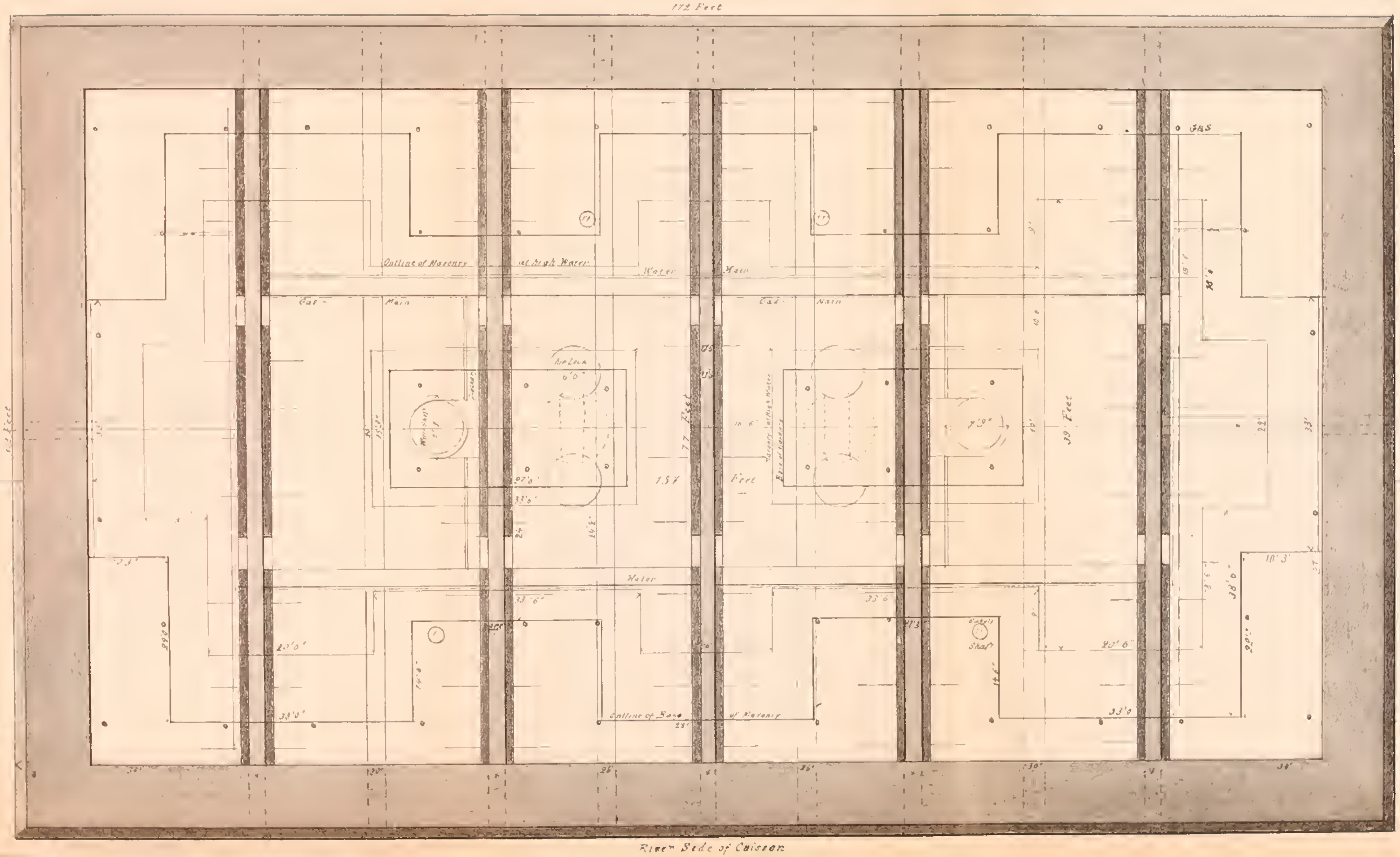
Excavating Machinery.

BROOKLYN CAISSON.

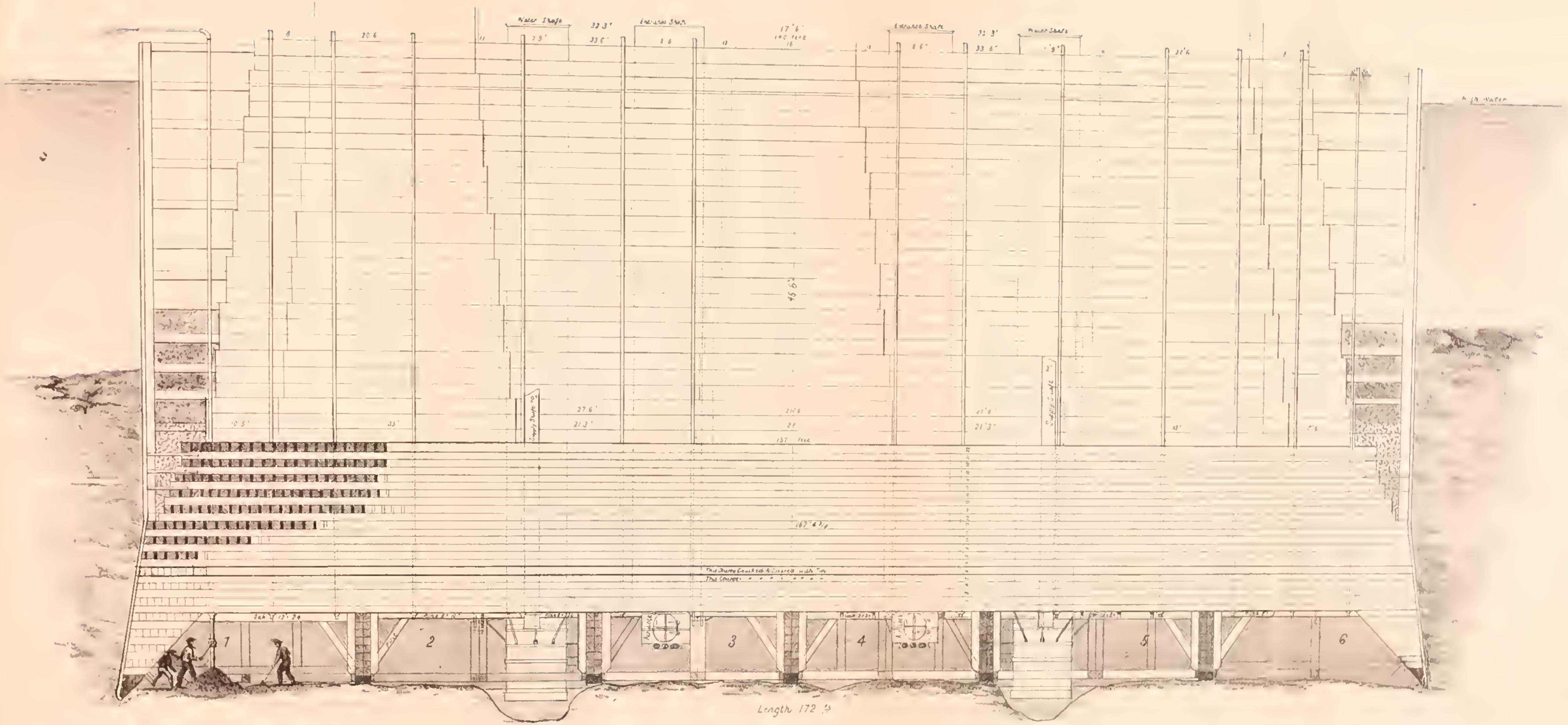
Engineer W A ROEBLING.

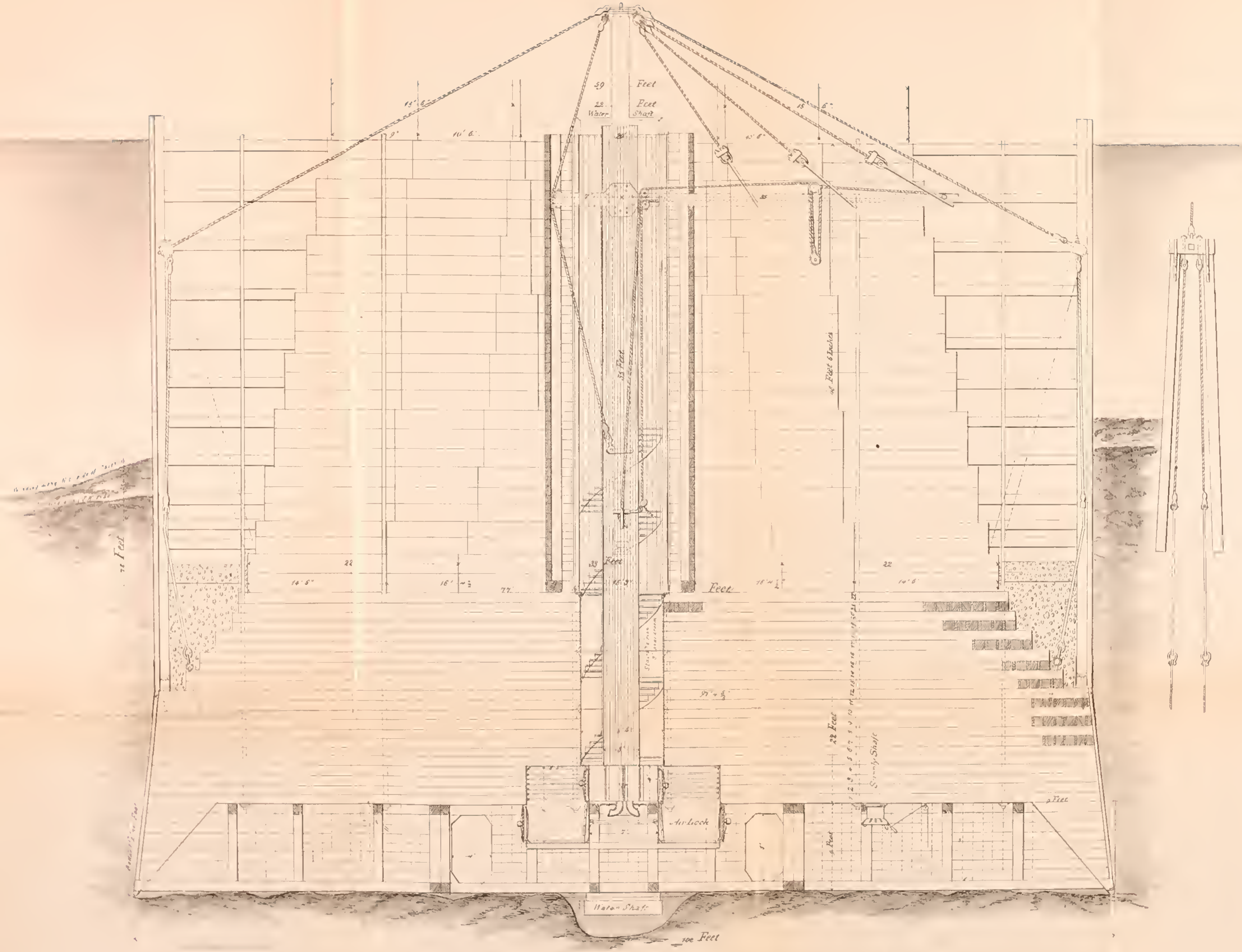


N. Y. CAISSON
HORIZONTAL SECTION
at Top of Air Chamber



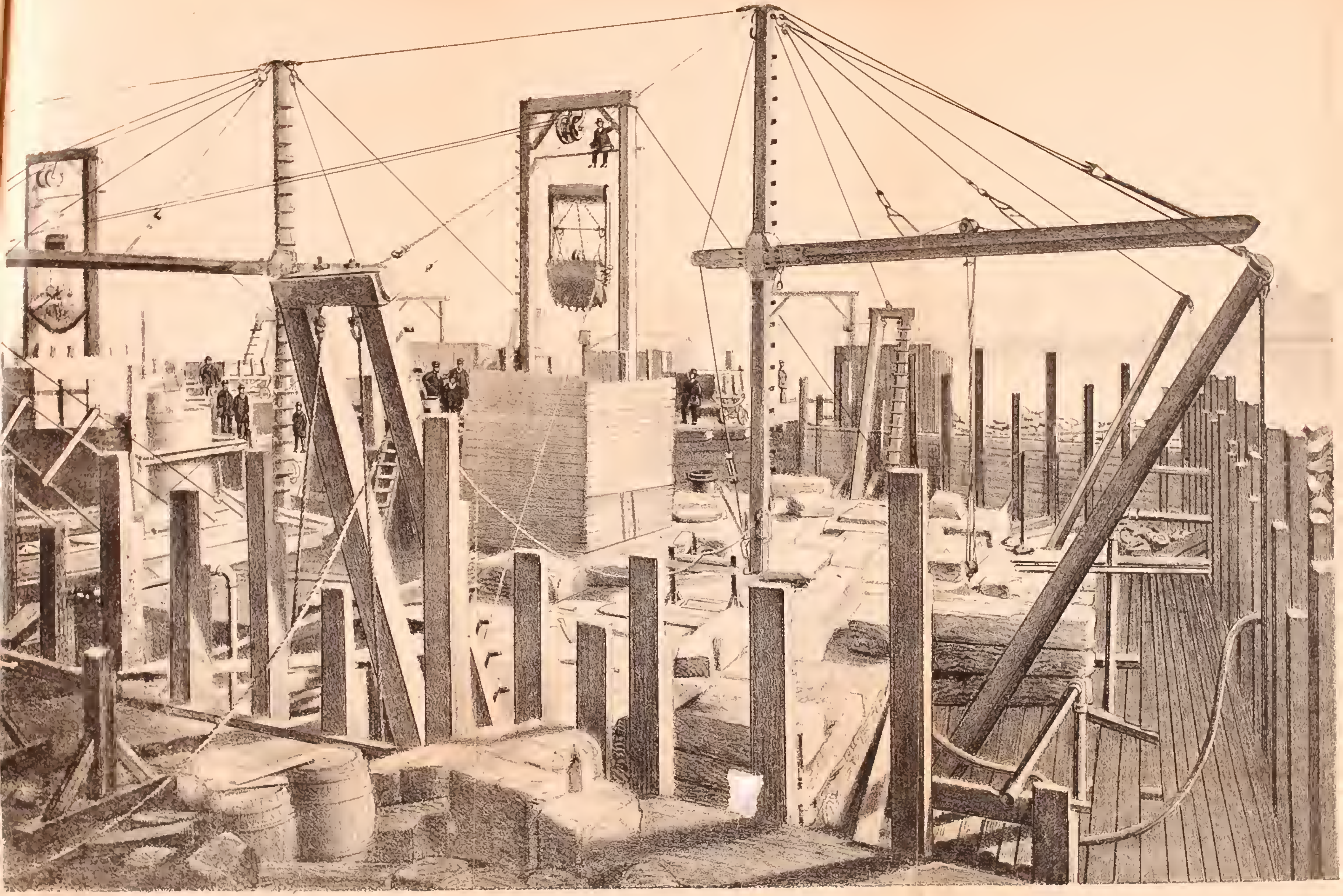
N.Y. CAISSON
LONGITUDINAL SECTION
10 Feet From Edge



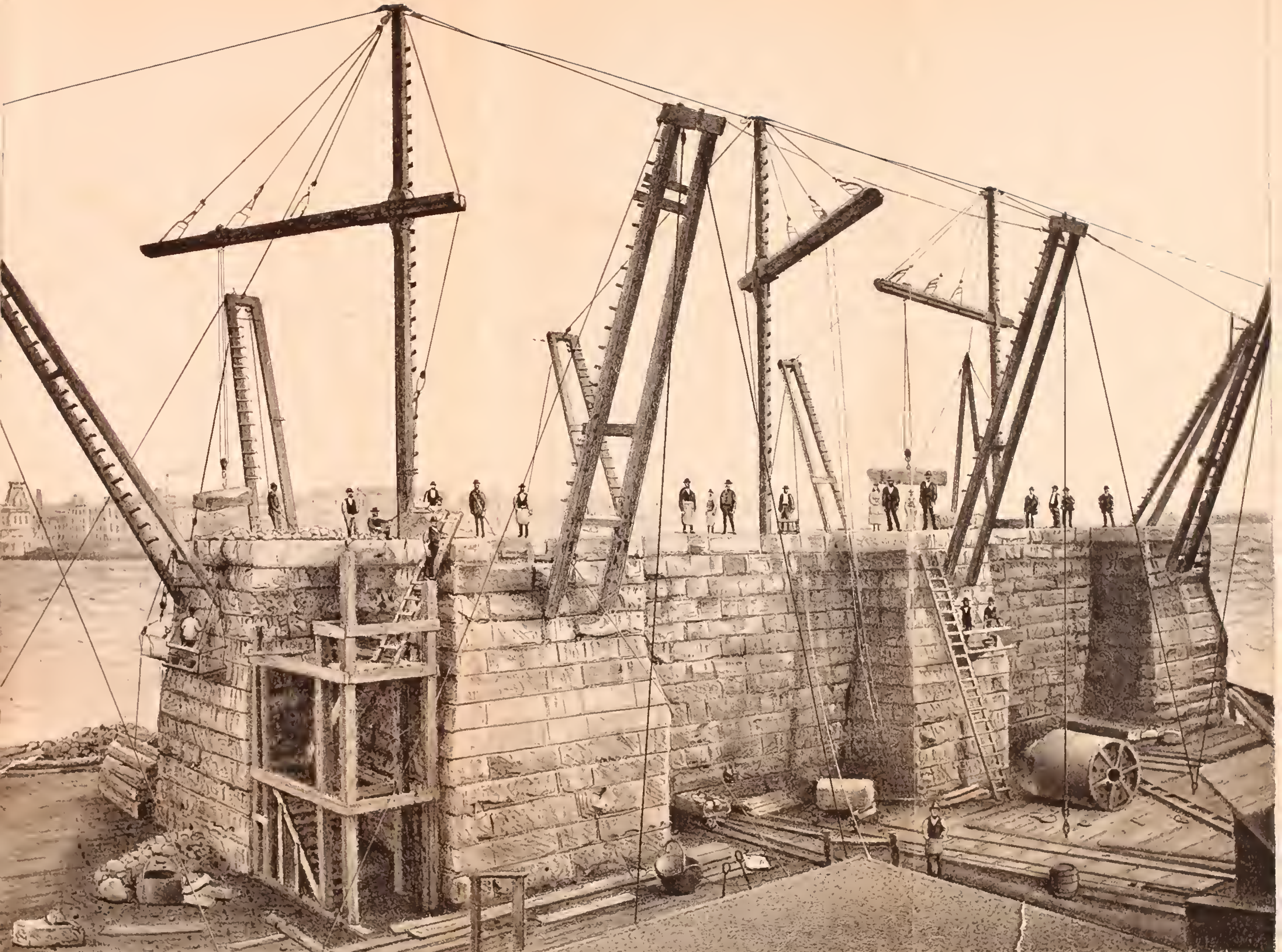


N. Y. CAISSON
TRANSVERSE SECTION.
through air locks.

Engineer W. A. ROEBLING.



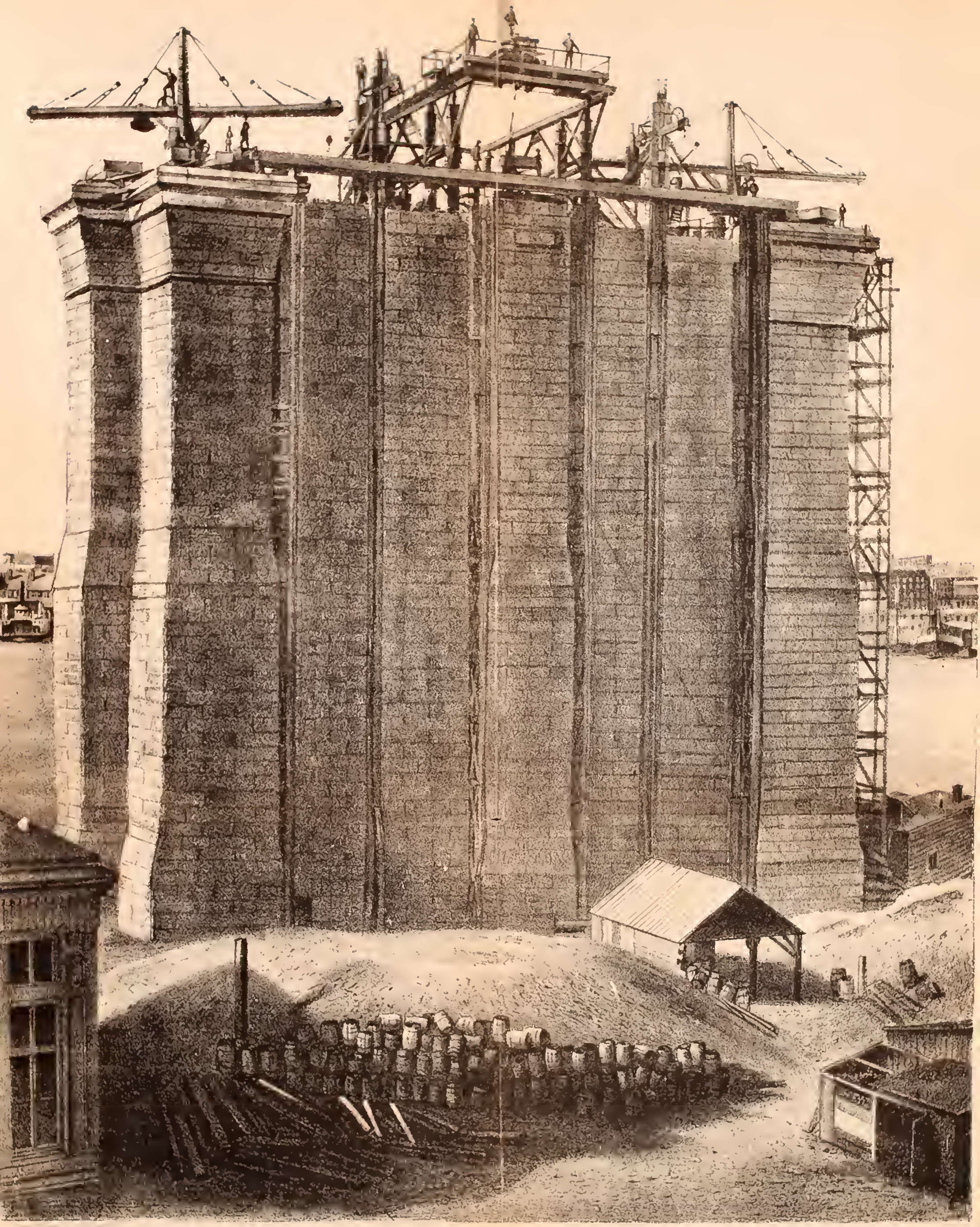
SINKING OF THE
NEW YORK CAISSON.
FEBY. 1872.
ENGINEER W. A. ROEBLING



NEW YORK TOWER.

SEPT. 1872.

ENGINEER W. A. ROEBLING.



BROOKLYN TOWER
Oct. 1872
ENGINEER. W. A. ROEBLING